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PREDICTION OF THE EFFECTS OF COMBINED AND SEQUENTIAL ENVIRONMENTS

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ABSTRACT

This project applies advanced techniques to determine the environmental competence of materials and equipments under combined and sequential environments experienced by Army systems and components in field operation. The critical aspect of environmental interaction, is thoroughly treated and integrated into the overall approach.

A plan is presented for receiving, organizing, and operating on the problem elements to yield the desired output of environmental effects prediction. The plan is specifically designed for computerization. The rationale is set forth in a logical, and comprehensive framework that may be readily understood and implemented by the potential user. A pilot exercise of the computerized prediction system gives specific examples of the system operation in specific instances.

Finally, conclusions and recommendations are offered regarding system practicality, usefulness, potentialities and limitations, and the guideposts presented for future action in the field of environmental effects prediction.

FOREWORD

This report summarizes the study of the application of computer techniques to the prediction of the effects of combined and sequential environments by a task team (G. Chernowitz, S.J. Bailey, S. Gurman, S.M. Levin) of The American Power Jet Company, under the supervision of George Chernowitz.

The work was performed for the U.S. Army, Frankford Arsenal, Philadelphia, Pennsylvania, under Contract No. DA 36-038-AMC-1784(A), under the supervision of Mr. David Askin and Mr. Maurice H. Simpson, in connection with Task No. 8 of Dept. of the Army Project No. DA 1V025001A622.

The project team is deeply indebted to Mr. Askin and Mr. Simpson of the Environmental Laboratory, Frankford Arsenal, for their cooperation and assistance in numerous regards.

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SUMMARY

Problem

The subject of combined and sequential environments has become increasingly important to the Army through a combination of significant changes in materiel requirements and management. Briefly these are:

1. Requirement for air mobility; implying minimum weight and the avoidance of overdesign and redundancy in all materiel.

2. Increase in complexity; implying many modes and levels of performance that must be tested.

3. Requirement that materiel be mobile worldwide and function in combinations and sequences of widely differing environments. Thus, the First Air Cavalry was moved from the dry plains of Fort Benning to the tropical rain forest and jungle of Vietnam; its materiel readiness must not suffer from this change in environment.

4. Budgetary constraints; requiring that materiel be procured at the lowest sound cost.

Conventional approaches to determining the effects of combined and sequential environments are time-consuming and require costly facilities. The problem attacked in this study is to determine whether the application of computer technology can short-circuit this process. In other words "Can a computerized system be used as an environmental test facility?"

Accomplishments

The report shows that a properly structured con-

cept using computers for the prediction of combined and sequential environmental effects is both feasible and shows promise of substantial economy in reduction of time and of facility costs. This key accomplishment is based on the attainment of a series of sub-objectives which have the effect of reducing the scale of computer and data requirements to a practicable level.

1. Ten natural and 12 induced environmental factors are shown to account for the environmental situations which affect Army materiel (See Report, page 4-5.)

   The computer system may therefore be furnished with one or more of the following inputs:

   Test Unit

   - Properties
   - Nomenclature

   Climatic Region

   - Time of year
   - Range of values

   Mission Profile

   - Logistic Phase
   - Operational Phase

   i.e., What is being used? Where is it being used? What is it doing?

   From these inputs information and results are given with regard to:

   Properties of constituent test units,
   Constituent environmental factors with ranges of values,
   Effects of environmental factors present,
   Additional properties and data of importance.

   These are provided on pages 3-16 through 3-17 of the report.

2. A systematic study of environmental factors acting in combination and sequence on Army materiel, reduce the pertinent number to a series of three matrices (pages 4-16 through 4-18) containing 157 combinations and 314 sequences of environments as being of practical importance. It is this technical research result that makes computerization feasible.

3. A hierarchy and appropriate classification of test units, as well as natural and induced environments has been established. This has the effect of permitting test results and predictor data developed for one level of equipment complexity to be applied to other similar items and constituent parts.

4. A means has been developed for treating the highly complex non-linear effects in actual environments and equipments by a technically correct linearization, thereby effecting a further decrease in computer requirements.

5. Test units have been organized in terms of their relationship to materials, parts, components, assemblies, and systems, (pages 5-2 and following), further reducing demands on computer size and capability.

6. System operation is illustrated by a series of demonstrations in which the computer determines factors, numerical and qualitative effects. All major system relationships are developed.

Finally, details of a pilot exercise are given, and a series of recommended demonstration tests set forth.

Conclusions and Recommendations

The conclusion is drawn that a practical and usable computerized system is feasible for predicting the effects of combined and sequential environments on Army materiel and equipments.

A strong recommendation is made that this line of investigation be further exploited to bring into practical application this new tool for achieving mission-essential results in a timely and economical manner.

CHAPTER I

INTRODUCTION

Definition and Philosophy of Environmental Problem

In recent years interest has grown in the effect on Army materiel of complex exposure situations involving combinations of environmental factors. This growing interest arises from a mounting concern for possible effects caused by unexpected interactions among environmental factors. It also reflects the increasing severity of environmental demands on current and future systems. These environmental effects, when they exist, may cause deterioration or failure much more rapidly than would be expected were they purely additive in an arithmetical sense.

In the service history of Army materiel, a large number of application loads, due to either induced or natural conditions, may occur. It is extremely difficult to predetermine the way in which these loads may become effective simultaneously, or the way in which one may follow another before the effect of the first has declined. Thus, a series of laboratory programs subjecting the equipment to individual exposures, recording that it has survived, may be misleading when it comes to actual field experience. An equipment may turn out to be quite incapable, for example, of sustaining a heavy impact after certain of its parts have been embrittled by radiation exposure.

The problem of combined or sequential environmental stresses presents grave difficulty in the variety of situations which would have to be tested, and the multitudinous volume of data which would have to be analyzed.

The purpose of this study was to "formulate analysis systems and techniques by which the effects of single and multiple environmental stresses in combination or sequentially can be predicted qualitatively and quantitatively by the use of electronic automatic processing systems (ADPS)".*

* Quotation from Project scope of work

At first glance this objective might appear attainable through the expedient of utilizing digital computers to organize the data, retain it in memory, and produce dependable assessments of complex effects. Preliminary study recognized that formulation of an effective computerized system depends on success in resolving a series of fundamental problem areas such as the following:

1. Handling large quantities of input data.
2. Classification of environmental factors, singly or in multiples.
3. Classification of Army materiel, taking into account the many levels of functional complexity ranging from materials to systems.
4. Efficient methods of analyzing stored data to yield useful answers to specific inquiries.
5. Isolation of variables associated with materials properties for the purpose of penetrating the significance of changes in environmental response.
6. Analysis of families of such variables to extract their major significance in terms of possible deterioration or failure under stated stress conditions.

Resolution of these problem areas places a premium on advanced techniques and methodology.

Previous related work in this area cited by the present scope of work, reported considerable advance. (References 1, 2, 3, 4, 5, 6.) Present status is that some estimates have been made as to classification in pairs of environmental factors having possible synergistic effect on one another. These estimates were generalized in that they did not identify sensitivity of particular materials or equipments. Corroborative testing, reported in reference 3, confirmed some of the conclusions reached in references 1 and 2. But it remains to <u>quantify</u> the effects on specific materiel of a broad variety of stress combinations and sequences.

PROGRAM LOGIC

In conformity with contract scope of work, research effort was organized in two main branches (See Figure 1-1):

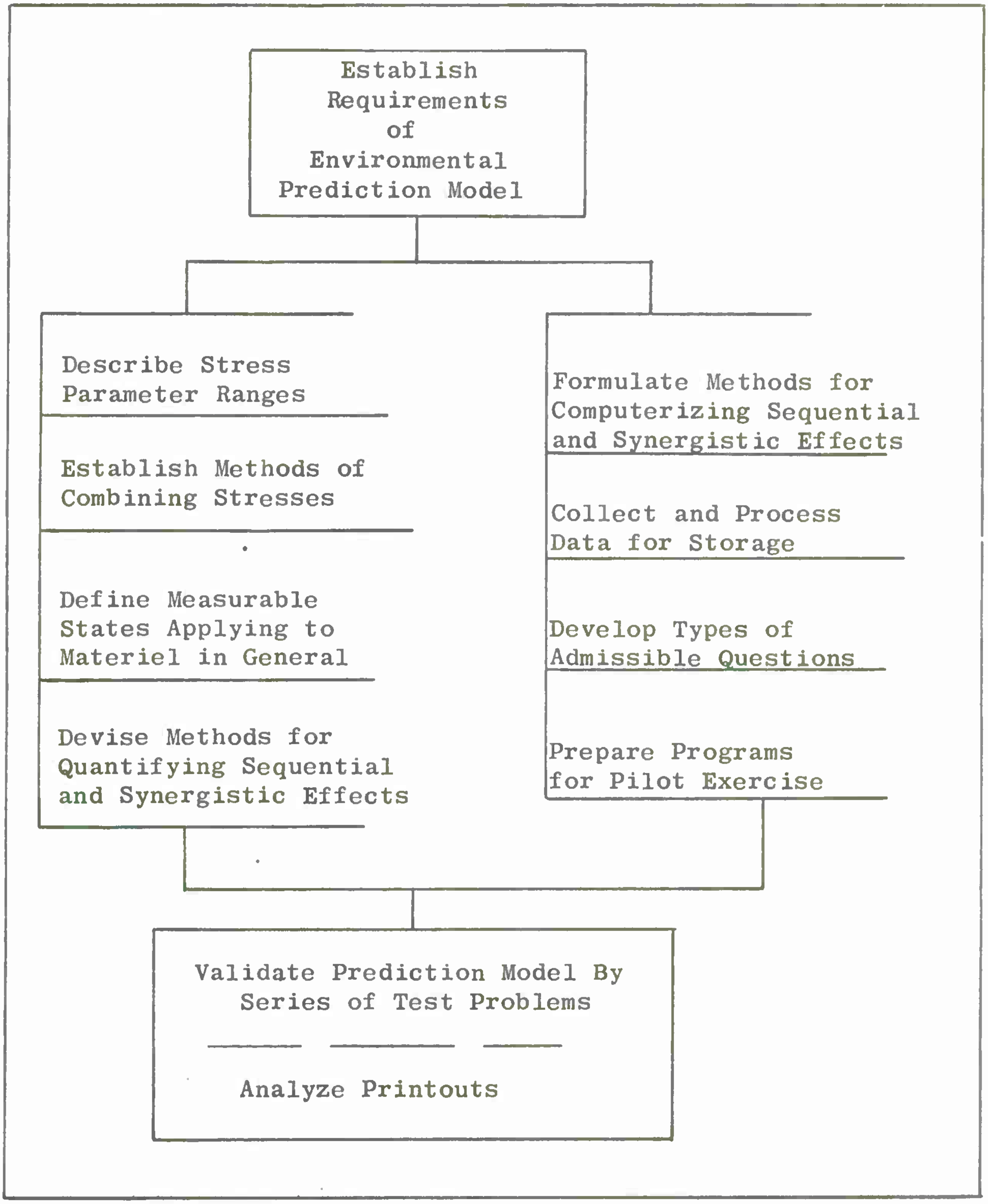

Figure 1-1. Logic Diagram

1. Investigation of environments and materiel, and the types of analytical operations which properly link them to produce valid estimates of exposure effects.
2. Investigation of computer techniques applicable to the analysis of single and synergistic environmental effects, and the required steps toward programs for conduct of a pilot exercise.

These two main divisions of effort were carried on concurrently, and eventually merged in a validation phase in which the finished prediction model was tested by submitting to it a series of test questions. Analysis of printouts in response to these test questions were then made to determine:

1. If the computerization of sequential and combined environmental effects appeared indeed to be practical.
2. If the variety of questions included in the exercise demonstrated the utility of the model to test engineers and personnel involved in equipment design and planning.

The first branch of the program required engineering analysis of environmental stresses to determine their measurable parameters and ranges through which these parameters might vary. After a suitable set of environmental stresses had been assembled and rigorously defined, it was necessary to establish pairs or groups of such stresses which would be likely to occur. This involved looking at the stresses from the viewpoints of:

1. Combinations of induced and natural environments,
2. Combinations of induced and induced environments,
3. Combinations of natural and natural environments.

In studying the problem of materiel, it was deemed advisable to categorize items according to equipment functional level, ranging from basic materials to complex mechanisms.

It was then necessary to establish an approach to measurement of property values, or other item variables whose fluctuation beyond admissible design ranges predict equipment deterioration or failure. The next step was to combine stresses with materiel by means of analytical operations based on available data, to make predictions of survival under single or synergistic situations.

The second branch of the effort involved analysis of computer techniques with emphasis on methods for storing and processing information on combined and sequential exposures. While this activity was being conducted, research was carried out in test activities and in the literature to assemble a suitable body of data which might serve for a pilot exercise.

From the view of those types of responses of value to test and design engineers, investigation led to the establishment of a list of admissible questions which were to be addressed to the prediction model. The final step in the second branch of the effort was to prepare programs for use in the input, processing, and output stages of pilot activity.

Results of these efforts merged in a prediction model representative of the type of machine capability described in the scope of work. The model was exercised by submitting a series of test questions. Analysis of printouts gave evidence of utility to technical personnel having environmental analysis problems.

SUMMARY OF REPORT CONTENT

I - Introduction

II - Discussion of Combined-Sequential Environmental Problem

This chapter contains a description of the difficulties encountered by design and test engineers engaged in product improvement and acceptance programs when they are confronted by the possible interaction among exposures likely to occur in the application environment. It analyzes the nature of information which would be most useful to them, and explores difficulties in achieving a systematic approach to computerization for reduction of repetitive and complicated testing. It brings to a focus the ultimate goal of assessing and improving environmental competence as a function of equipment behavior in environments complicated by combined or sequential occurrence.

III - Prediction of Environmental Effects

The fundamental structure of a prediction model is specified in this chapter. The process of structuring the model involves analysis of the way in which computer techniques might be applied to prediction of materiel response to complex exposure. The applicability and advantages of using computer techniques are fully explored. A system approach is adopted; that is, the materiel is considered as if it were passing through an actual exposure experience. In this way, the various matrices stored in the computer can be looked at as "chambers" through which the materiel passes, undergoing a proper program of stresses to simulate actual life conditions. Many aspects of single and multiple environmental factors, including synergistic effects, are treated. Synergisms are considered to mutually inhibit one another, mutually augment one another, also possibly inhibit from one to another, and augment in the reverse direction. The chapter concludes with a preliminary discussion of computer system capabilities, thus effecting an early reduction of the problem concepts to specific techniques for processing.

IV - Environmental Factor Sets

The work of Arnold, referenced in the Scope of Work, is briefly discussed and the problem areas where his analyses concluded are defined. (References 1 and 2.) Representative environmental factors are listed with details of parameters and numerical ranges. Rationale for pairing environmental factors is explained, including how environmental effects are analyzed for combined factors whose measurement units are dissimilar. In the case of synergistic pairs, the usefulness of introducing a third (hybrid) term is examined. To maximize the analytical coverage of the various sequential phasing alternatives, the sample space of sequential phasing exposures is examined in terms of the following possibilities:

1. Occurrence of environmental factor A at any time up to the occurrence of environmental factor B

affects the way materiel responds to environmental factor B. (In referring to environmental factor A or B it is presumed that suitable intensities and time duration of exposure are specified.)

2. Integration of the cumulative effects of environmental factor A (specified intensity and duration) up to the time environmental factor B occurs, affects the way in which materiel responds to environmental factor B.
3. A situation similar to item 2 except that the synergistic effect of environmental factor A is changed by continuing recovery of the test unit up to the time environmental factor B occurs.

V - Organization of Materiel

Materiel is organized on a hierarchy basis, ranging from basic materials through components and assemblies to systems. The investigation is channeled towards specific types of test units for illustrative purposes. The APJ choice of materiel for study is particularly responsive to equipment in use by the Army. The environmental competence of parts common to different assemblies is arrived at by a search path which shifts from the general to the particular; that is, it moves automatically down the hierarchy until it reaches the desired item which may belong to many different types of equipment. The chapter concludes with a careful examination of the problem of setting up states or physical properties which may be used in response to the statement of work to structure the required prediction potential.

VI - Description of System Operation

This chapter delineates the way in which the request for information and the resulting response is handled in terms of computer technology. The problem content is fitted within the framework of normal constraints of computer techniques. Methods of input-output system operation are discussed in addition to processing of searched data to create prediction responses.

VII - System Pilot Exercise

This chapter deals with the construction of programs and the insertion of collected data to prepare a series of test runs. A suitable list of questions is submitted to the prediction model and the resulting printouts are analyzed to assess feasibility of the method.

VIII - Tests

This chapter discusses the usefulness of tests in support of the computerized system prediction capability. Various tests, proposed for illustrative purposes, are described. Projections of resulting environmental effects are detailed for those tests selected by the Frankford Arsenal test facility as a validation exercise.

IX - Conclusions and Recommendations

In this chapter the nature of the feasibility conclusion is described and a number of recommendations for further work in the area are presented.

CHAPTER II

COMBINED-SEQUENTIAL ENVIRONMENTS PROBLEM

The purpose of this research is to devise methods by which automatic data processing techniques might be used to predict combined and sequential environmental effects. These effects-predictions are to be in either quantitative or qualitative form.

In this chapter the groundwork is laid for specific-solution approaches to the "combined-sequential prediction" problem. To this end a number of problem elements are discussed, with focus on the feasibility of using ADPS (Automatic Data Processing System) techniques. Test units are hypothetically exposed to environmental situations by means of operational programming to search out from machine memory the best available data, or best interpretation of incomplete data which can be furnished as a useful prediction of test unit response to the particular situation. The pros and cons of applying machine techniques are explored at some length and the groundwork laid for a more comprehensive discussion of prediction rationale and technical approach appearing in Chapter III.

PROBLEM ELEMENTS

The following aspects of the overall problem are discussed in this section:

(a) Uncertainties encountered in single and multiple environmental situations.
(b) Contrasting characteristics of combined and sequential environmental effects.
(c) Deterministic and statistical aspects of effects prediction.
(d) Utility of both quantitative and qualitative responses.
(e) Constraints of automatic data processing techniques.

Uncertainties Encountered in Environmental Situations

By "environmental situation" is meant an event or series of events whose occurrence may deteriorate or ultimately fail a material or an equipment. A single environmental situation is one in which the effect of only one of the surrounding environmental conditions is of interest in predicting test unit response. Such a situation is contrasted with the case in which multiple environmental conditions are of interest in predicting test unit response.

There are two kinds of uncertainties involved in such situations:

1. The uncertainty that the event, or series of events, may occur
2. The uncertainty, given the event does occur, that the response of the test unit will result in deterioration, or possibly ultimate failure.

In the discussion which follows, the first of these uncertainties is determined by a study of the mission profile. The assumption is made that the event does actually occur, and therefore is certain. It is with the second uncertainty that the discussion is concerned.

At first glance the approach of analyzing single environmental situations appears rewarding. It has long been the practice in conventional test facilities, highly instrumented for accuracy and equipped for realism, to subject materials or equipment to environmental conditions in which a single environmental factor was increased in intensity to make a comparison between the response of a test unit under elevated (operational) stress and its response under "laboratory" conditions.

The serious problem which arises with data obtained piecemeal, from a succession of single environmental situations simulated in the laboratory, is the uncertainty of producing a reliable prediction without knowing how one operational stress might have affected test unit response to the other, had they both been present during the simulation. This outstanding aspect of the problem has led to many experiments involving two or more environmental factors, in attempts to adequately simulate multiple environmental situations.

Uncertainties to be encountered in multiple environmental situations are numerous and are discussed in more detail in the following section.

Distinctions Observed in Combined and Sequential Effects

The phrase "combined and sequential" is often used rather loosely in referring to the following variety of multiple environmental situations:

1. Two stresses applied to a test unit at the same time and for an equal duration of exposure (i.e., combined),
2. Partial time overlap in the application of two stresses to a test unit (i.e., combined and sequential),
3. Application of a second stress to a test unit after the first stress has been suspended (i.e., sequential). Alternative results would be:

    (a) Application of the first stress has left no after-effect.
    (b) The second stress is applied before the test unit has completely recovered from the effect of the first stress.
    (c) The second stress occurs some time after the first stress and the test unit has not and will not recover from the effects of the first stress.
4. More complex situations patterned after the above examples, involving more than two environmental factors.

Synergism occurs when the multiple stresses interact, whether time overlapping or not, in such a way as to change the response of the test unit to either one or both, from what the response would have been had either one or both been acting singly.

An initial problem which arises in studying the prediction difficulties associated with such situations is the manner in which environmental factors might be classified to facilitate handling combined or sequential experiences, and to assist in application of machine techniques. Analysis of this problem leads logically to consideration of the way in which environmental factors may be treated in pairs or triplets from the viewpoint of likelihood of occurrence, in such combinations or sequences. Considerable effort is devoted in this report to arriving at logical methods for predicting and treating such pairs. Charts are provided showing logical pairing of:

1. Induced with induced,
2. Natural with natural,
3. Induced with natural.

Where it can be determined that some kind of synergistic effect occurs when two or more environmental factors occur in combination or sequence, a problem arises as to how to treat such nonlinear effect. If there are two environmental factors, A and B, synergism may occur in either direction. Environmental factor A, for example, may change the response of a test unit to environmental factor B, or vice versa. These two effects may occur simultaneously, so that environmental factors A and B may be termed mutually synergistic. A tentative approach to treating synergistic effects which may become quite complex, and may be partially masked by non-synergistic responses of test units, have been studied. One approach is to treat a synergistic effect as an additional or "hybrid" environmental factor. Proceeding in this manner would introduce a convenient device for analyzing, in turn, higher order interaction terms, such as the synergistic effect between two synergistic effects.

Due to the varieties of measurement units associated with various environmental factors, and the often extreme variation in intensity and normal time duration between one environmental factor and another, it is apparent that combined sequential situations may attain vast proliferation. A further problem then arises, treated further in the paragraphs below, in regard to the size of the equipment memory and complexity of software (program material) which would be needed to successfully handle and process associated data.

Deterministic and Statistical Aspects of Effects Prediction

The word "prediction" is used in this report in a broad sense. Stating it another way, the problem of making useful predictions of test unit responses to an environmental situation is approached both deterministically and statistically. The emphasis is on predictions based on relatively deterministic information, that is, analysis of data which results in fairly certain conclusions about the responses of test units. To an extent, as might be expected, some of the predictions will represent inferences drawn from deterioration expectations.

The statistical aspect of the term "prediction" suggests to the prospective user of such a service that, as adequate statistics become available on the performance of test units in environmental situations, such data may be assimilated to provide additional confirmation or adjustment to the stored statements relating to environmental effects.

Utility of Quantitative and Qualitative Responses

The problem of prediction formulation also includes the question of relative utility of quantitative, as opposed to qualitative responses. Should attempts be made to assign some kind of quantification to every bit of stored data or information? Or where actual quantification is not available, is it useful to have statements available, for example, of environmental threat to particular materials or equipment without exact statements of frequency, time duration, intensity and other deterioration thresholds?

It must be recognized that the problem of achieving useful formulations of test unit response prediction, which provide tractable direction to the user, is greatly magnified by the scarcity of properly oriented, quantitative data on combined-sequential environmental situations.

Constraints of Automatic Data Processing Techniques

Early in the study, during analysis of the needs of a demonstration exercise, the problem arose as to the allowable flexibility in formulating questions to a computerized system. It was obvious that the user could not be allowed to formulate questions at random. Some constraints were necessary in respect to:

1. Technical areas for the exercise,
2. Approaches to phrasing test unit responses to stated environmental situations,
3. Categories of test units on which questions were to be allowed,
4. Formats of environmental descriptions,
5. Nature and volume of stored data processing to be allowed.

These constraints were not only pertinent to the demonstration exercise, but must be examined as well for application to the ultimate full-scale system.

While the feasibility of applying ADPS techniques to produce useful information on the interactions among environments and test units was never seriously in doubt, many problems were recognized in respect to devising practical methods for such application. These problems are discussed further in the paragraphs below.

System Concept of Effects Prediction

In this section the system approach and typical problems are discussed. By system approach is meant analysis of the prediction problem as if it were a process or system which is under design or synthesis. There is definite advantage to such an approach in that well defined, logical procedures may be followed in establishing a system concept, and in testing it for effectiveness.

One might think of the test unit, or population thereof, as a black box which is to be "disturbed" by input signals in the form of environmental stresses. The output could be looked upon as the test unit response. This is illustrated in Figure2-1. On the other hand, it is convenient to think of the computerized system as an analytical simulator of a variety of environmental situations. In this case, the input signal becomes the test unit itself, properly described in terms of a design plan or test requirement.

The latter approach is taken in this report, and developed at some length in the next chapter. It will be discussed briefly in this chapter to bring out some of the problems involved, at the same time "touching base" with the specifics of the work statement.

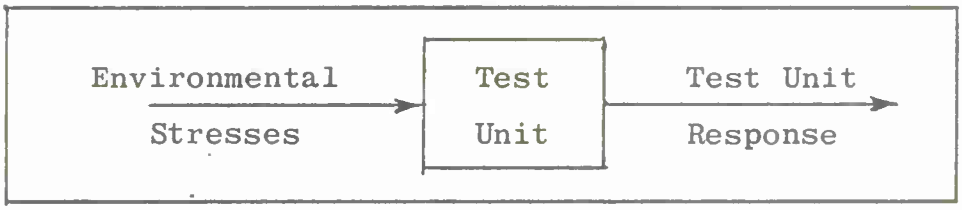

Figure 2-1. Systems Approach Diagram of Environmental-Effects Prediction System

Environmental Descriptions

The difficulty arising at the outset of the study involves the endless variations of materials, equipment functions and possible exposure responses which constitute the vast body of data to be controlled. It is obvious that a great deal of judgment must be used to reduce the storage problem.

Approaching the matter from the viewpoint of Specification MIL-D-70327, approved methods of classifying equipment from the design viewpoint are available. However, it does not necessarily follow that the letter of this specification should be adhered to in organizing and describing test units for environmental information purposes. It may well be that an entirely different way of approaching classification would suit the computerization better. Moreover, it should be borne in mind that such classification schemes are not mandatory to the process of consigning data to computer memory; they are only convenient means of organizing system thinking, and possibly supplying categorical groupings to shorten some aspects of search.

The statement of work has drawn attention to the importance of establishing the "state" of test units. Arnold presented one type of state taxonomy. The question arose early in this study as to the applicability of this particular taxonomy, and the desirability of simplifying, if possible, classification of response variations to environmental stimuli under various "state" headings.

Such an approach appeared extremely interesting and was subjected to careful analysis. When it was attempted to apply the ideas directly to specific hardware, the problem began to assume different proportions: It was found that generalizing about environmental effects, without actually naming and examining specific hardware, was not a viable approach.

Effort was therefore directed during the study to isolating a fair-sized block of actual materiel (materials and equipments), and describing it sufficiently to supply a sizeable set of data for use in a computer exercise, including hardware descriptions, level of complexity and function, response to environmental situations, and relationships among steps in the hierarchy (so that materials, for example, might be traced up to assemblies and parts). This approach was effective in that it did not sidestep any of the issues involved because it comprised a complete consideration of a practical environmental problem. Conclusions were thus drawn for the large universe of test units by examining an adequate sample.

System Operational Considerations

Assuming that environmental and test unit descriptions have been adequately stored in the memory and are subject to recall in an organized fashion, the next consideration of importance is the manner in which these two bodies of data impinge upon one another, including the nature of analytical processing which goes further than simple matching or linking of data from the two main categories.

Certain critical linkage may exist between test units and exposure configurations, possibly in the form of stored "hazard pairs". The concept of a hazard pair is the exposure of a particular material to a given intensity of environment, wherein a critical warning signal is developed during the search process. The exposure aspect of the hazard pair may be stated in terms of combined or sequential stress, as appropriate.

The problem becomes more acute when simple statements of such hazards cannot be made in deterministic language. So many variables often enter a situation of environmental response that relatively straightforward statements are vulnerable and open to question. It often becomes necessary to introduce a probabilistic statement, such as, "in the described situation 60% of the population is expected to fail".

Thus framing a query content, within the bounds of a logical information exercise, can become extremely complex.

Implications in Computerization

In reference to paragraph three of the Work Statement, "the analytical techniques for solving environmental problems are to be those in which specific characteristics of environments and of material are catalogued and stored in the memory of an electronic computer. These characteristics are to be recalled and applied as required by the program of a specific problem."

These requirements are rather specific. The question arises as to the feasibility of storing sufficient environmental and material information, using discrimination and selection to make the process practicable. The general implications have been discussed in the paragraphs above.

Software having the programmatic capability of satisfying the above requirements would appear to evolve from rather straightforward program writing. However, there is an evident risk that the end product would be little more than an automated handbook or catalog of environmental information. Investigation of the problem indicates the importance of establishing a computerized service, providing the design or test engineer with a more highly organized data product than would be otherwise available to him. The answer seems to lie in the sophistication of arrangement in memory and recall analysis. Here lies the major opportunity for taking advantage of modern high-speed digital computer techniques so the resulting system would not be merely a high-class filing system.

But computerization does not automatically furnish a panacea for complexity. Rather, if not carefully controlled in concept, it may result in greater proliferation of both hardware and software. Furthermore, the essential problem of combined-sequential prediction does not abruptly succumb to computerization per se.

It is true that mechanized analytical simulation of complex environmental situations, as they affect selected test units, may yield a means for controlling a large body of interacting, complex environmental situations. Advantage may be taken of this characteristic of computerization in the present instance. But the little understood manifestations of physical phenomena such as are involved for example, in synergistic situations, are not likely to be resolved by application of pure deterministic equations or other analytical techniques. The situation is no different here from what it has been in any aspect of physical science. The models, which explain deterministically or probabilistically the behavior of physical things are first proposed in theory and then tested in fact.

It was expected that as the study continued, some light would be shed upon the ways in which computer techniques might contribute to separating synergistic effects from other events which may occur, and which may not constitute actual synergism.

A case in point is the familiar test where a population is submitted to environmental factor A, to environmental factor B, and to a combination of the two. Three identical populations are assumed under test. If the linear sum of members failed by A alone and by B alone is not equal to the number of members failed by A and B acting together, the difference might be assumed to be the load-increasing or load-decreasing synergism. But, unfortunately, in the third case there may be some members of the population that would have been failed by A, or by B, acting alone, entirely aside from the interaction between A and B.

The above example is mentioned to indicate that the application of computerization to combined and sequential environmental situations is by no means a clear-cut procedure. Careful attention must be given to the masking aspects of each situation to avoid erroneous conclusions.

CHAPTER III

PREDICTION OF ENVIRONMENTAL EFFECTS

Fundamental Problem Involved in Effects Prediction

The fundamental problem of an environmental effects prediction system is to derive either qualitatively or quantitatively the effect of an environmental situation on a test unit. That is, the system should be capable of predicting how any given test unit will be affected by any environmental situation it could possibly encounter during its existence. That is, of course, an enormous problem. To make the problem more tractable, a system should be designed which is capable of handling only those test units and environmental situations which are of interest to the particular user of the system.

A system which only yields qualitative results serves a partial function to the user. A qualitative prediction is a quick method of generally determining whether or not a test unit is susceptible to an environmental situation (single, combined or sequential). However, qualitative statements do not provide an explicit relationship between the intensity level of the environmental exposure and the amount of effect on the test unit, nor the ranges of the environmental factor to which the test unit is susceptible. At best, a qualitative prediction warns of possible trouble areas of using test units in environmental situations.

To yield quantitative predictions, the system must examine the physical and chemical properties of the test unit, or its operating characteristics. Only through this approach can quantitative relationships between environmental factors and test units be established. At the materials level of test units, the actual chemical and physical material properties are examined as a function of values of environmental factors (single, combined, or sequential). For higher levels of test units (parts, components, assemblies, and systems) the properties investigated are the operating characteristics of the test unit. For example, the gain of a transistor would be such a parameter under consideration. The susceptibility of a test unit to an environmental factor is measured as the quantitative effect the environmental factor has on the test unit's property or operating characteristic.

For satisfactory operation of the test unit, the values of the properties or operating characteristics must remain within certain tolerance limits. When these values stray outside the limits due to an environmental load, the test unit does not function correctly in that environmental situation. The quantitative environmental prediction system can therefore predict when, why, and by how much a test unit will function correctly or not for a given environmental situation.

The environmental-effects prediction system may be accomplished by numerous methods. In fact many exist today that are known by other names. A typical prediction system in common use today consists of an engineer looking up the characteristics of a test unit in a handbook. The handbook supplies the engineer with equations which he then evaluates for the specific conditions of his problem. The result is, in effect, a prediction of how the test unit in question will function in a given situation. If the equation were a relationship of the test unit's characteristic as a function of environmental factors, then the system would indeed be an environmental-effects prediction system.

The aforementioned "system" is actually an example of a simplified manual prediction system where the information look-up and prediction computations are done completely manually.

Many sophistications of this basic manual "prediction system" are possible, but basically, the general approach of the system remains the same; i.e., look-up of the required relationship and evaluation of the relationship for the stated conditions of the problem. The method by which these tasks are accomplished is determined by the sophistication of the system. In general categories, these methods may be classified as:

1. manual

2. semi-automatic
3. fully automatic.

Numerous variations exist within each category. The semi-automatic system is one in which a computer is used to perform some of the tasks, while others are done manually. The greater the sophistication of the system, the more it utilizes a computer to perform its routines. For example, some systems will locate the required relationships by a manual search routine but evaluate these relationships on a computer, while others may use a computer to locate the relationships and then use manual techniques to evaluate them.

The ideal, fully automatic prediction system utilizes a computer to perform all the tasks of the system. The user merely feeds his problem into the system, which then performs all the necessary routines and prints out the result to the user.

An underlying task of an environmental-effects prediction system is the derivation and storage of the quantitative relationships. The possibilities for accomplishing this goal, range from manual to fully automatic means. In the fully automatic system, raw data on the test unit property vs. the environmental factor is supplied to the system, which automatically processes it to derive the necessary relationships; these are then automatically stored for use in a prediction problem.

Applicability and Advantages of Computerization

Computerization is seen to be directly applicable to the functions of an environmental-effects prediction system. In fact, most of the basic routines utilized in the projected system are already being run as separate routines on computers. For example, computers are used to determine analytical expression approximations to data points by "least-square" programs. Computerized information storage and retrieval systems are also in widespread use. Also, computers are often used to solve and evaluate equations.

The enormity of the amount of data handled by the system poses some storage problems. However, efficient storage and retrieval routines are available or can be developed to overcome these difficulties.

Beside the advantages of a computerized system in ease of operation, accuracy, and speed in obtaining results, other benefits of computerization include such aspects as automatic data-updating, and availability of system results to personnel not capable of performing the necessary analysis manually.

Single and Multi-Environmental Stresses-Combined/Sequential Phasing

Three distinguishing cases may be considered for the phasing application of environmental stresses. The first of these, called a single environmental stress or factor, consists of <u>one</u> environmental factor at given level (below or above some reference level) while all other present environmental factors are kept at the nominal reference level. *, **. It should be noted that usually more than one environmental factor will be present in a given environmental situation; however, for purposes of analysis and model development, only stressed level environmental factors (levels above or below nominal value) will be considered as acting on the test unit. For example, when a test unit is said to be acted upon by the environmental factor "radiation", it is understood that the ambient temperature is at a reference level of say 60°F, the ambient pressure is at a reference level of 14.7 PSI, the ambient relative humidity is at a reference level of 40%, and so on for all other present environmental factors. The environmental factor "radiation" however is at some stressed level.

* Environmental factor is an element, natural or induced, which contributes to the aggregate of surrounding environmental conditions or influences.

** A reference level of an environmental factor is the reference point to which other levels of the environmental factor are measured. This concept is well established in various areas of physics. For example, the reference voltage level in an electrical field, and the reference entropy level in thermodynamics.

The second case occurs when the test unit is subjected simultaneously to two or more environmental factors, which are at a stressed level, while all other environmental factors present are at their respective reference levels. This case is called a combined environmental factor situation.

The third case occurs when the test unit is subjected in sequence to two or more environmental factors, which are at a stressed level, while all other environmental factors present are at their respective reference levels. This case is called a sequential environmental factor situation.

Any combination of the three aforementioned cases may occur to form a complex environmental situation. A case in which all three are incurred would be an application of environmental factor x from t = 0 to t = 4, and environmental factor y from t = 2 to t = 6. Hence from t = 0 to t = 2 there is only single factor x present; from t = 2 to t = 4 combined factors x and y are present, as well as sequential factors x and x- and -y combined. From t = 4 to t = 6 sequential factors x, x- and -y combined, and y are present. It is seen here that a sequence of environmental factors may consist of single or combined environmental factors. This example is illustrated in figure 3-1.

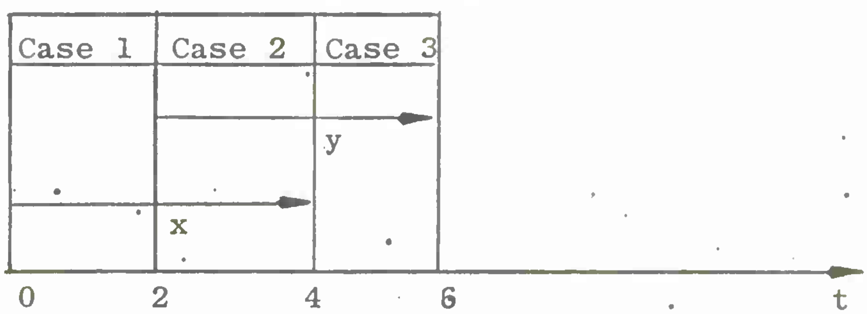

Figure3-1. Illustration of Single, Combined, and Sequential Environmental Factors

In dealing with the alternative phasing application situations, the critical problem of data availability arises. Although most realistic environmental situations are cases 2, 3 and combinations of 1, 2 and 3, most available data is for case 1, the single environmental factor situation. Little quantitative data is available for cases 2 and 3. The data which is available for these cases is usually qualitative, or if quantitative, it is usually sporadic and limited.

The analytical expression of combined and sequential environmental situations will be covered in greater detail in this Chapter. Chapter IV will further discuss combined and sequential environmental factors respectively, and will also discuss a computerized model for predicting combined and sequential environmental factor effects on test unit properties.

Synergistic Problem

The origin of the word synergism is a theological doctrine that the human will works together with the divine spirit in the process of regeneration. In medical terminology, synergism has come to mean the working together of one bodily organ or medicine with another. The field of environmental sciences has borrowed the term synergism to denote the additional (beneficial or deleterious), non-linear effect on a test unit from two or more environmental factors acting simultaneously or in sequence. (Reference 9)

When two or more environmental factors attack a test unit simultaneously or in sequence, two possible phenomena may result. The first or simple linear effect is the addition of the two single effects. In mathematical terms this may be expressed as

$$G\ (x,\ y) = f_1\ (x) + f_2\ (y) \tag{1}$$

Where: f_1 (x) is the effect on the test unit of environmental factor x alone,

f_2 (y) is the effect on the test unit of environmental factor y alone,

G (x,y) is the effect on the test unit of environmental factors x and y.

This linear case exhibits no synergism as the effect on the test unit of the two environmental factors combined, or in sequence, G (x,y) is the same as the addition of the effects on the test unit of the two environmental factors acting alone, f_1 (x) and f_2 (y) respectively.

This may be looked upon as analogous to a linear electrical network where the principle of superposition holds. That is, given a linear electrical network, L, shown in Figure 3-2,

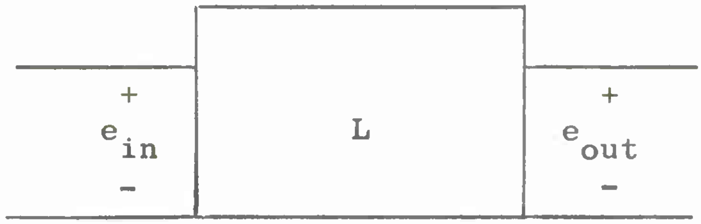

Figure 3-2. Linear Electrical Network

the superposition principle states that the result of applying two inputs e_{in1}, and e_{in2} to the network in combination is to yield an output, e_{out}, which is the addition of the outputs due to inputs e_{in1} and e_{in2} taken alone, e_{out1} and $e_{out\ 2}$.

Mathematically this can be expressed by the following relations:

$$\text{Given } e_{out\ 1} = f\ (e_{in\ 1}) \tag{2}$$

$$e_{out\ 2} = f\ (e_{in\ 2}) \tag{3}$$

$$\text{let } e_{in} = e_{in\ 1} + e_{in\ 2} \tag{4}$$

$$\text{and } e_{out} = f\ (e_{in}) \tag{5}$$

then

$$e_{out} = f\ (e_{in}) = f\ (e_{in\ 1} + e_{in\ 2}) \tag{6}$$

and by the superposition theorem

$$f\ (e_{in\ 1} + e_{in\ 2}) = f\ (e_{in\ 1}) + f\ (e_{in\ 2}) \tag{7}$$

therefore

$$e_{out} = f\ (e_{in\ 1}) + f\ (e_{in\ 2}) = e_{out\ 1} + e_{out\ 2} \tag{8}$$

which is analogous to equation (1) for environmental factors.

An exception to the rule should be noted as it applies to environmental analysis also. The following electrical network is also considered to be linear, although equation (8) does not hold exactly as is.

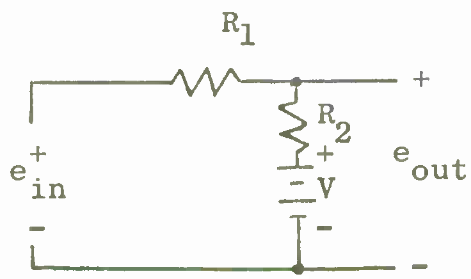

Figure 3-3. Electrical Network Containing Constant Source.

Applying source $e_{in\ 1}$ as an input to the network of figure 3-3 the output $e_{out\ 1}$ is given by:

$$e_{out\ 1} = \frac{e_{in\ 1} R_2}{R_1 + R_2} + \frac{VR_1}{R_1 + R_2} \qquad (9)$$

which is seen to be a term due to source $e_{in\ 1}$ plus a constant term which is present regardless of the presence of $e_{in\ 1}$, i.e.:

$$e_{out\ 1} = f\ (e_{in\ 1}) + K \quad . \qquad (10)$$

Similarly applying source $e_{in\ 2}$ as an input to the network of Figure 3-3 the output $e_{out\ 2}$ is given by:

$$e_{out\ 2} = \frac{e_{in\ 2} R_2}{R_1 + R_2} + \frac{V R_1}{R_1 + R_2} \qquad (11)$$

$$\text{or } e_{out\ 2} = f\ (e_{in\ 2}) + K \qquad (12)$$

so that the output is a term due to source e_{in2} plus the same constant term as in the output from source e_{in1}. Note this constant term is an inherent characteristic of the network.

Now if sources $e_{in\ 1}$ and $e_{in\ 2}$ were applied simultaneously to the network the output, e_{out} would be given by

$$e_{out} = \frac{e_{in\ 1} R_2}{R_1 + R_2} + \frac{e_{in\ 2} R_2}{R_1 + R_2} + \frac{VR_1}{R_1 + R_2} \tag{13}$$

or

$$e_{out} = f\ (e_{in\ 1}) + f\ (e_{in\ 2}) + K \tag{14}$$

Since

$$e_{out\ 1} + e_{out2} = f\ (e_{in\ 1}) + f\ (e_{in\ 2}) + 2K \tag{15}$$

it is seen that $e_{out} \neq e_{out\ 1} + e_{out\ 2}$

due to the repeated constant factor; however, if the constant factor is dropped from the analysis and is tagged on at the end, the network obeys the rules of a linear network, and the principle of superposition holds. That is:

$$e'_{out} = e'_{out\ 1} + e'_{out\ 2} \tag{16}$$

and

$$e_{out} = e'_{out} + K \tag{17}$$

Similarly in an environmental effects analysis, a test unit property may have some inherent constant value when no environmental factors are acting on it. This constant value adds on to any value the property may take on due to an environmental factors action.

For example, assume the variation of property z of a test unit due to environmental factor x may be given by the relation

$$z = f_1\ (x) = 5x^2 + 10\ x + 25 \tag{18}$$

where the constant, 25, is an inherent value of the property z with no environmental factors acting on it. The variation of property z with environmental factor y is assumed to be given by :

$$z = f_2\ (y) = 10\ y^2 + 35\ y + 25 \tag{19}$$

As seen, the constant term, 25, is still present

Now the added effects of environmental factors x and y are given by adding the right sides of 18 and 19, that is:

$$f_1(x) + f_2(y) = 5x^2 + 10x + 10y^2 + 35y + 50 \quad (20)$$

By doing this it is seen that the constant factor, 25, has been added on twice.

The actual relationship of property z vs. environmental factors x and y combined or in sequence is given by:

$$z = G(x, y) = 5x^2 + 10x + 10y^2 + 35y + 25 \quad (21)$$

which carries the constant term only once
hence in actuality

$$G(x, y) \neq f_1(x) + f_2(y)$$

However if the constant term is dropped from the analysis, as in the electrical network analysis, and added on at the end so that:

$$f'_1(x) = f_1(x) - 25 = 5x^2 + 10x \quad (22)$$

$$f'_2(y) = f_2(y) - 25 = 10y^2 + 35y \quad (23)$$

then $G'(x, y) = f'_1(x) + f'_2(y)$ (24)

or $G'(x, y) = 5x^2 + 10x + 10y^2 + 35y$ (25)

and $G(x, y) = G'(x, y) + 25$ (26)

or $G(x, y) = 5x^2 + 10x + 10y^2 + 35y + 25$ (27)

In this manner, the above case can be treated as the simple linear case where the modified principle of superposition of single environmental effects holds. That is, an altered equation (1) applies:

$$\begin{aligned} G(x, y) &= G'(x, y) + K \\ &= f'_1(x) + f'_2(y) + K \end{aligned} \quad (28)$$

where: $G'(x, y) = f_1'(x) + f_2'(y)$

is the effect on the test unit property by environmental factors x and y with the common constant value, k, substracted.

$f'_1(x) = f_1(x) - k$ is the effect on the test unit property by environmental factor x alone with the common constant value, k, subtracted.

and $f'_2(y) = f_2(y) - k$ is the effect on the test unit property by environmental factor y alone with the common constant value, k, subtracted.

The second or non-linear case, which occurs when an additional effect results due to the combination of the two environmental factors acting on the test unit, simultaneously or in sequence, is the synergistic case. In this instance the mathematical expression for the resulting phenomena can be written as:

$$G(x, y) = f_1(x) + f_2(y) + f_3(x, y) \tag{29}$$

where: $f_1(x)$ is the effect on the test unit of environmental factor x alone.

$f_2(y)$ is the effect on the test unit of environmental factor y alone.

$G(x, y)$ is the total effect on the test unit of environmental factors x and y acting in combination or sequence.

and $f_3(x, y)$ is the additional effect on the test unit due to the action of environmental factors x and y acting in combination or in sequence. This term would not occur if the environmental factors acted singly. It is the actual synergistic term.

In this non-linear case, purely additive superposition of single environmental factor effects to obtain combined and sequential environmental factor effects is invalid.

However, this case may be looked upon as analogous to a non-linear network which may be analyzed by the use of controlled sources to account for the additional non-linear effects. For example, given a non-linear network, N, shown in Figure 3-4,

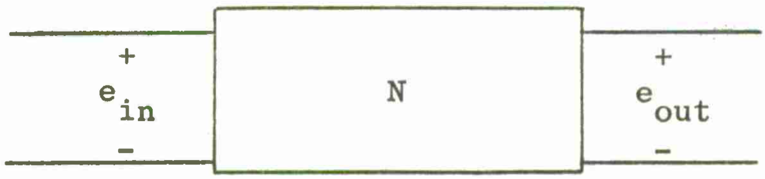

Figure 3-4. Non-Linear Electrical Network

the network may be broken down for analysis as seen in Figure 3-5.

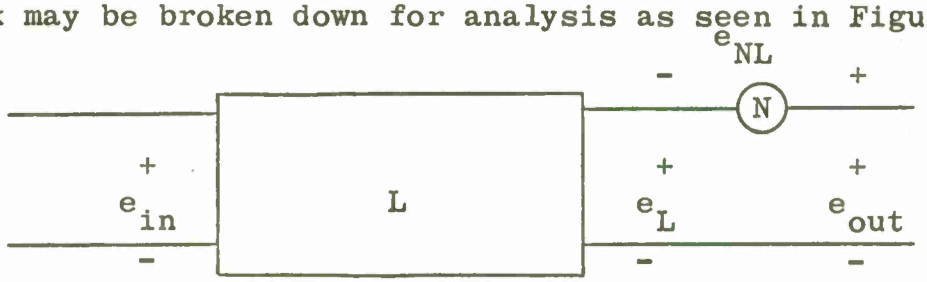

Figure 3-5. Pictorial Model for Analyzing Non-Linear Network.

In this network it is seen that

$$e_{out} = e_L + e_{NL} \tag{30}$$

where:

$e_L = f(e_{in})$ is the output of the linear part of the network,

and e_{NL} is the additional output of the network due to non-linearities.

To keep the analogy similar to the environmental analysis, it is assumed that the non-linear term, e_{NL}, only takes on value when two or more signals are fed into the input. That is, e_{NL} is assumed = 0 for one input.

Suppose a signal, $e_{in\ 1}$, is a lone input to the network: the output, e_{out}, is given by

$$e_{out_1} = e_{L_1} = f\ (e_{in_1})\ . \tag{31}$$

Next, suppose that a second signal, e_{in_2}, is a lone input to the network. The output, e_{out_2}, is given by

$$e_{out_2} = e_{L_2} = f\ (e_{in_2})\ . \tag{32}$$

Finally, suppose both signals are applied simultaneously to the network such that

$$e_{in} = e_{in_1} + e_{in_2}\ . \tag{33}$$

From equation (30), is seen the output, e_{out}, given by

$$e_{out} = e_L + e_{NL}\ , \tag{30}$$

Since e_L is the linear part of the output, by the superposition theorem,

$$e_L = f\ (e_{in}) = f\ (e_{in_1} + e_{in_2})$$

$$= f\ (e_{in_1}) + f\ (e_{in_2}) \tag{34}$$

Hence, $e_{out} = f(e_{in_1}) + f(e_{in_2}) + e_{NL}\ .$ (35)

Since $e_{NL} = f_1\ (e_{in_1},\ e_{in_2})$ equation (35) can be written as

$$e_{out} = f\ (e_{in_1}) + f\ (e_{in_2}) + f_1\ (e_{in_1},\ e_{in_2})\ . \tag{36}$$

Equation (36) is seen to be analogous to equation (29) for environmental factors.

It should be noted that in this non-linear case, inherent constant values are treated just as in the linear case to avoid their being added on twice. That is, they are subtracted and added on at the end. The constant term, however, occurs only in the linear term, e_L .

Revising equation (36) to hold for the case of an inherent term,

$$e_{out} = f'(e_{in_1}) + f'(e_{in_2}) + K + f_1(e_{in_1}, e_{in_2}) \quad (37)$$

where:

$f'(e_{in_1}) = f(e_{in_1}) - K$ is the output from the linear part of the network due to source e_{in_1} with the inherent constant output level K subracted.

$f'(e_{in_2}) = f(e_{in_2}) - K$ is the output from the linear part of the network due to source e_{in_2}, with the inherent constant output level K subtracted.

K is the inherent output from the network which is present with or without any input signal.

$f_1(e_{in_1}, e_{in_2})$

is the output from the non-linear part of the network.

Hence the environmental factor equation (29) can be transformed to an equation similar to (37) to handle the case where an inherent test unit property value is present. The resulting equation would be:

$$G(x, y) = f'_1(x) + f'_2(x) + K + f_3(x, y) \quad (38)$$

$$\text{where } f_1'(x) = f_1(x) - K \quad (39)$$

$$\text{and } f_2'(x) = f_2(x) - K. \quad (40)$$

To illustrate this case assume: property z of a test unit varies with environmental factor x according to

$$z = f_1(x) = x^2 + 15x + 10. \quad (41)$$

Property z varies with environmental factor y according to

$$z = f_2 (y) = 2y^2 + 30y + 10. \tag{42}$$

Property z varies with environmental factors x and y (in combination or sequence) according to

$$z = G (x, y) = x^2 + 15x + 2y^2 + 30y + 12xy + 10. \tag{43}$$

It is seen that K=10 and from equations (39), (40) the following results:

$$f_1' (x) = x^2 + 15x \tag{44}$$

$$f_2' (y) = 2y^2 + 30y . \tag{45}$$

Therefore, from equation (38)

$$f_3 (x, y) = 12xy \tag{46}$$

results as the synergistic term.

The problem of prediction of this synergistic term by computerized techniques will be covered in Chapter VI, Section B of this report.

General Description of Computer System Capabilities.

The computerized environmental prediction system should have the ability to catalog and store information on test units and applicable environmental conditions on which it operates to predict the effects of environmental factors on test unit.

The hierarchy of test unit levels which the system handles are:

1. Material
2. Part
3. Component
4. Assembly
5. System

The environmental envelope the system is capable of handling are:

1. Regional Locations
2. Environmental factors - natural and induced
   a. Single
   b. Combined
   c. Sequential

The typical inputs which the system is capable of handling, with the respective outputs are outlined in Figure 3-6. which is followed by examples illustrating the various cases outlined in the table.

CODE	INPUT	OUTPUT
I A	Test Unit	Properties (with numerical values)
I B	Test Unit, some properties (with numerical values)	Other properties (with numerical values)
I C	Test Unit, Properties	Numerical values of properties
I D	Test Unit	Constituent test units (one level below)
II A	Climatic Region	Constituent environmental factors (with ranges of values)
II B	Climatic Region, Time of year	Constituent environmental factors (with ranges of values for that time of year)
II C	Climatic Region, Environmental factors.	Ranges of values of those environmental factors
II D	Climatic Region, Environmental factors, time of year	Ranges of values of those environmental factors for that time of year.
II E	Environmental factors, Ranges of Values	Other environmental factors and their ranges of values.
III A	Test Unit, Climatic Region	Environmental Factors present, their ranges of values, Test unit properties, Effects of the Environmental factors

Figure 3-6a. Summary of System Capabilities

CODE	INPUT	OUTPUT
		present on the Test Unit's properties
III B	Test Unit, Climatic Region, Time of Year	Environmental Factors present, their ranges of values for that time of year, Test Unit Properties, Effects of the Environmental Factors present on the Test Unit's properties for that time of year
III C	Test Unit, Climatic Region, Environmental Factors	Ranges of values of these Environmental Factors for the climatic region, Test Unit properties, Effects of the Environmental factors on the Test Unit's properties
III D	Test Unit, Climatic Region, Environmental Factors, Time of Year	Ranges of values of these Environmental factors for the Climatic Region for that Time of year, Test Unit properties, Effects of the Environmental Factors on the Test Unit's properties
III E	Test Unit, Environmental Factors (No Ranges of Values given)	Test Unit properties, Qualitative Effects of Environmental Factors on Test Unit's Properties
III F	Test Unit, Environmental Factors (With Ranges of values)	Test Unit Properties, Effects of the given Environmental Factors on Test Unit Properties
III G	Test Unit, Test Unit Properties Environmental input as in III A, B, C, D, E or F.	Output as in III A, B, C, D, E or F but Effects only on given Test Unit Properties
III H	Test Unit, Test Unit Properties, the ranges of values of some of these properties Environmental input as in III A, B, C, D, E, or F	Output as in III G but effects on properties due to other properties having certain values as well as effects due to environmental factors are included.

Figure 3-6b. Summary of System Capabilities (Cont'd.)

System Capabilities

I. Input concerning test unit alone.

A. Input test unit and obtain list of relevant properties, obtain numerical values and/or ranges under standard laboratory conditions where possible. (Test unit levels 1, 2, 3, 4, 5.)

Example: Input: Oil Capacitor
Output:

Property	Range or Value
Capacitance	.05 mfd. - 12 mfd.
Voltage rating	600 - 50,000 volts D.C.
Maximum operating temperature	125° C
Dielectric constant	

B. Input test unit and some relevant properties including values, and obtain values for other relevant properties where possible by solving equations. In cases where this is not possible obtain a listing as in part A. (T.U. levels 1, 2, 3, 4, 5.)

Example: Input: Glass capacitor
Dielectric constant = 6
Plate area = $5 \times 10^{-2} cm^2$
Distance between plates = 2×10^{-1}cm

Output:

$$\text{Capacitance} = \frac{KA}{36 \times 10^{11} \pi d} = \frac{6 \times 5 \times 10^{-2}}{3.6 \times 10^{12} (3.14)\ (2 \times 10^{-1})} \qquad (47)$$

Capacitance = .132$\mu\mu$f

Property	Range or Value
Voltage rating	500 PWV
Maximum operating temperature	

C. Input test unit and specific properties of concern. Obtain listing as in A, but only for those properties listed in the input. (T.U. levels 1, 2, 3, 4, 5.)

Example: <u>Input:</u> Tantalum capacitor
Capacitance range acceptable
Maximum acceptable operating temperature

<u>Output:</u>

Property	Range or Value
Capacitance	.033 Mf - 4000 Mf
Maximum operating temperature	125^{o} C

D. Input test unit and obtain breakdown of constituents one level below. (T.U. levels 2, 3, 4, 5.)

Example: <u>Input:</u> I.F. amplifier (level 3)

Output: $\left.\begin{array}{l}\text{Triode or transistor}\\ \text{Capacitor}\\ \text{Resistor}\\ \text{Inductor}\end{array}\right\}$ level 2

II. Input concerning environment alone.

A. Input climatic region, obtain list of natural environmental factors (single, combined and sequential) prevalent in that region, with year-round ranges of values for these factors where possible.

Example: <u>Input:</u> Arctic

<u>Output:</u>

Environmental Factor	Range or Value
Temperature	$-40^{o}F$ to $60^{o}F$
Blowing snow	1.5 to 3 in./mo.
Winds	0 to 40 mph
Temperature condensation	etc

Environmental Factor	Range or Value
Low temperature - blowing snow (combined)	etc
Low temperature - winds (combined)	
Low temperature - temporary condition (combined)	
Low temperature - snow - wind (combined)	
Snow - low temperature (sequential)	
Snow - wind (combined)	

B. Input climatic region and specific time of year, obtain list of natural environmental factors (single, combined, sequential) prevalent in that region for that time of year, with ranges of values at that time of year for these factors.

Example: Input: Continental, July

Output:

Environmental Factor	Range or Value
Temperature	$50^{o}F$ to $95^{o}F$
Rain	.8 in/mo to 5.8 in/mo
Sand and dust	etc
Fungus	etc
Relative humidity	
Temperature-rain (combined)	
Rain-sand and dust (combined)	

C. Input climatic and specific environmental factors, obtain year-round values or ranges of only these factors.

Example: Input: Desert, Temperature, Relative humidity

Output:

Environmental Factor	Range or Value
Relative humidity	$50^{o}F$ to $100^{o}F$
Temperature	15% to 80%

D. Input climatic region and specific environmental factors for a specific time of the year, obtain values or ranges for only those factors for that time of year.

Example: Input: Tropical, Relative humidity, Temperature, July

Output:

Environmental Factor	Range or Value
Relative humidity	70% to 100%
Temperature	65°F to 90°F

E. Input Environmental factors with their values, obtain values of other environmental factors by means of calculations (equations and charts).

Example: Input: Wet bulb temperature 70°F, dry bulb temperature 90°F, barometric pressure 29.92 in Hg.

Output: From carrier equation and steam tables obtain relative humidity.

III. Inputs concerning test unit and environment.

A. Input test unit and climatic region. The computer selects all natural environmental factors and their ranges or values prevalent in the given climatic region. The output is a prediction of environmental effects of the test units' properties (test unit may be at levels 1, 2, 3, 4 or 5), depending upon data stored in the computer (types of information to be explained later).

Example: (Note the information used here is hypothetical).

Input: Transformers, Desert and Steppe

Output: Transformer-Temperature:

(1) Unsatisfactory operation of transformer may occur at temperatures above 180°F.

(2) Coil winding resistance decreases exponentially with temperature decrease

$$R = R_o^{\;-K(T_o - T)} \qquad (48)$$

From env. table, $T_o = 60^oF$ std. ref. temp.
From T.U. table, R_o value given; K value given; R may be calculated for range of T for this problem.

(3) Rapid drop in temperature causes cracking of potting compounds and terminal bushings.

<u>Transformer-Moisture</u>

(1) Moisture promotes corrosion of windings. (See Figure 3-7.)

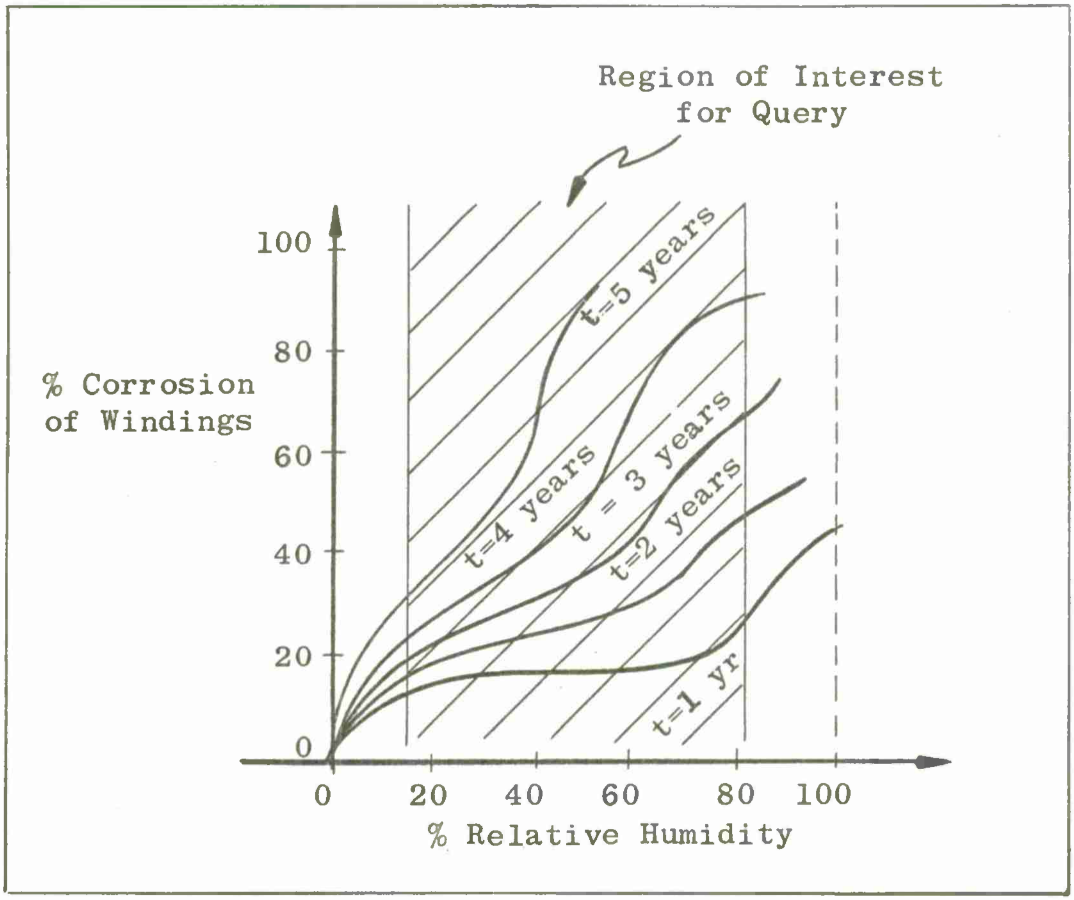

Figure 3-7. Plot of Corrosion vs. Relative Humidity for Transformer Windings

(2) Moisture supports fungus growth in windings.
(3) Dielectric strength of insulation decreases with moisture. (See Figure 3-8.)

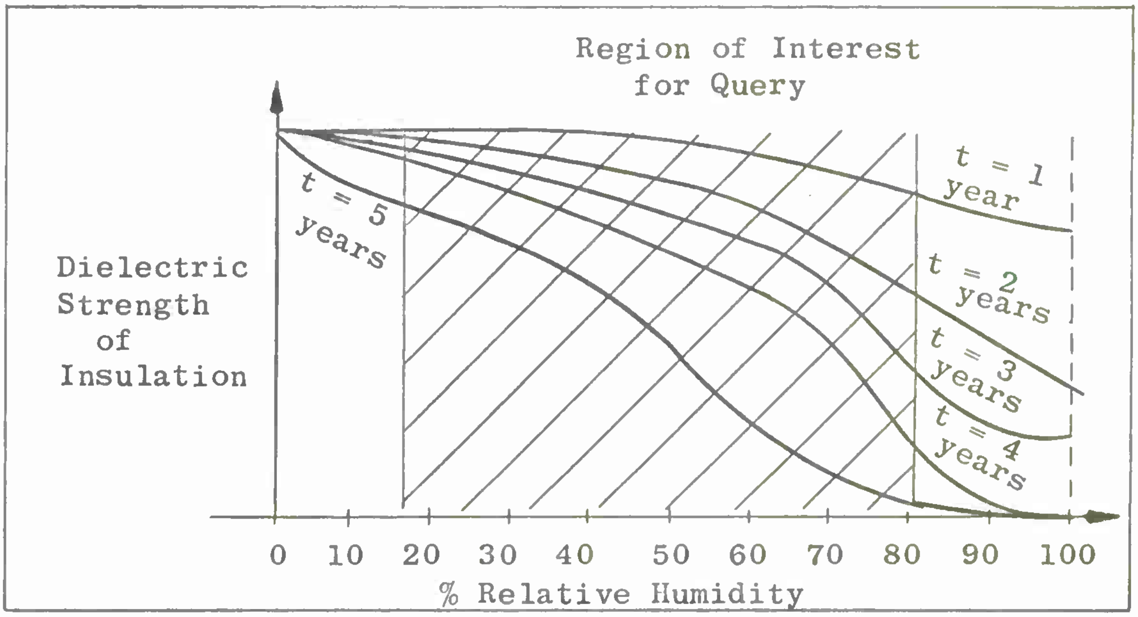

Figure 3-8. Plot of Insulation Dielectric Strength vs. Relative Humidity

Transformer-Sand and Dust

(1) Not affected.

Transformer-Temperature, Humidity (combined)

(1) Dielectric strength of insulation decreases faster with high temperature and humidity combined than with temperature. (See Figure 3-9.)

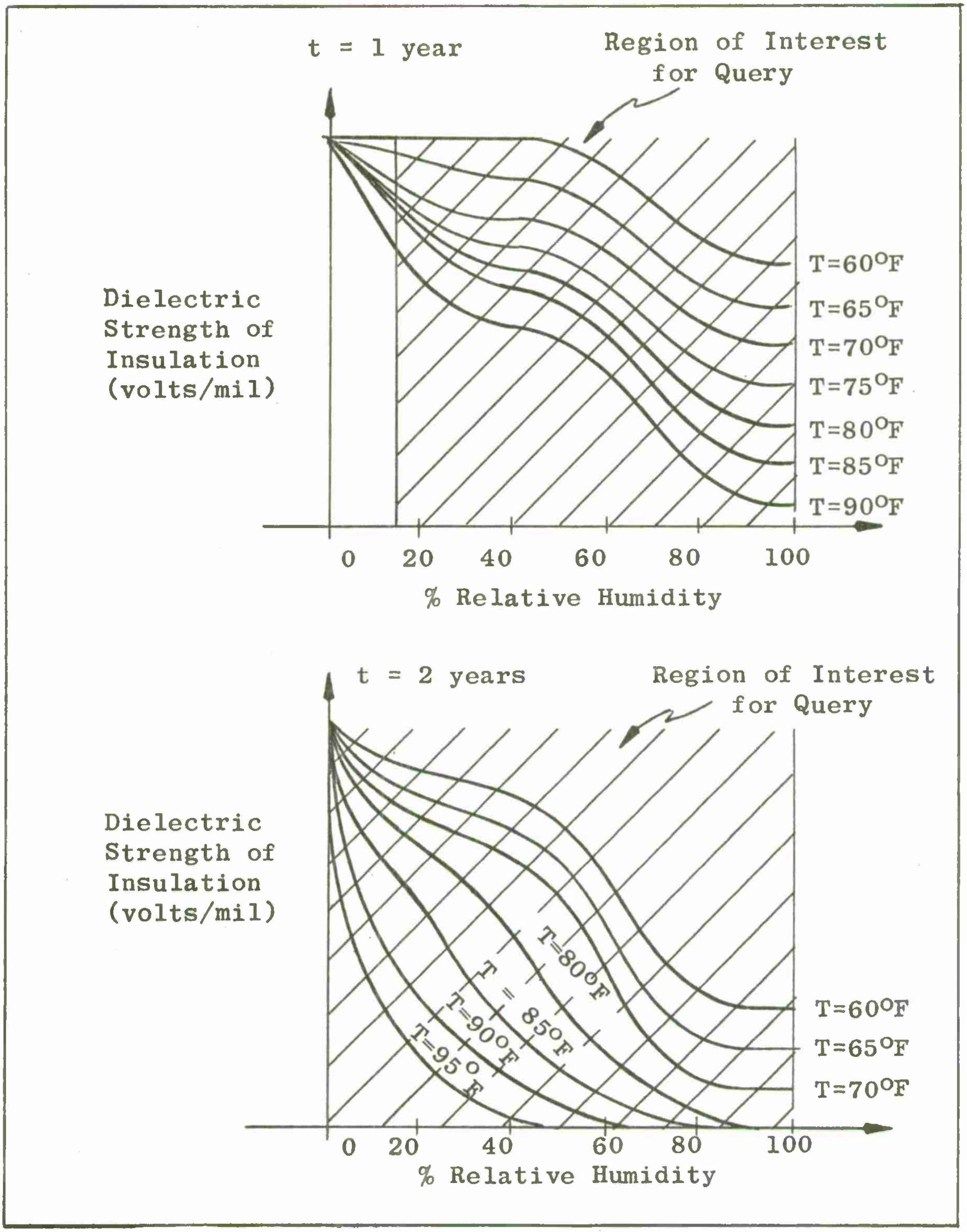

Figure 3-9. Plots of Insulation Dielectric Strength vs. Relative Humidity and Temperature

B. Input test unit, climatic region and specific time of year. The computer selects all natural environmental factors and their ranges or values prevalent in the given climatic region for that time of year. The computer uses this to predict effects on the test unit's properties for that specific time of year, depending on the data stored in the computer.

Example: Input: Transformer, Continental, July

Output:

Transformer-High Temperature

(1) No serious trouble for this range of temperature ($70^{\circ}F$ to $80^{\circ}F$).

Transformer-Moisture

(1) Moisture promotes corrosion of windings. From Figure 3-7, Transformer-Moisture (1), 10 to 20% of winding should corrode in this environment, in one year, where relative humidity range is 55 to 80% for July.
(2) Moisture supports fungus growth in windings.
(3) Dielectric strength of insulation decreases with moisture (see Figure 3-8, Temperature-Humidity (3)) range of relative humidity here is 60 to 80%.

Transformer-Sand and Dust

(1) Not affected.

Transformer-High temperature, Humidity (combined)

(1) Dielectric strength of insulation decreases faster with high temperature and humidity combined than with temperature alone (see Figure 3-9, Transformer-Temperature Humidity combined (1), range of relative humidity is 60 to 80% for this problem).

C. Input test unit, climatic region and specific environmental factors. The computer selects year-round ranges of values for these environmental factors for that climatic region and uses these to predict effects on the test unit's properties depending on the data stored in the computer.

Example: Input: Electrolytic capacitor, Arctic, Moisture, Low temperature

Output:

Electrolytic capacitor-Moisture

(1) Moisture decreases dielectric strength of fixed capacitors. (See Figure 3-10.)

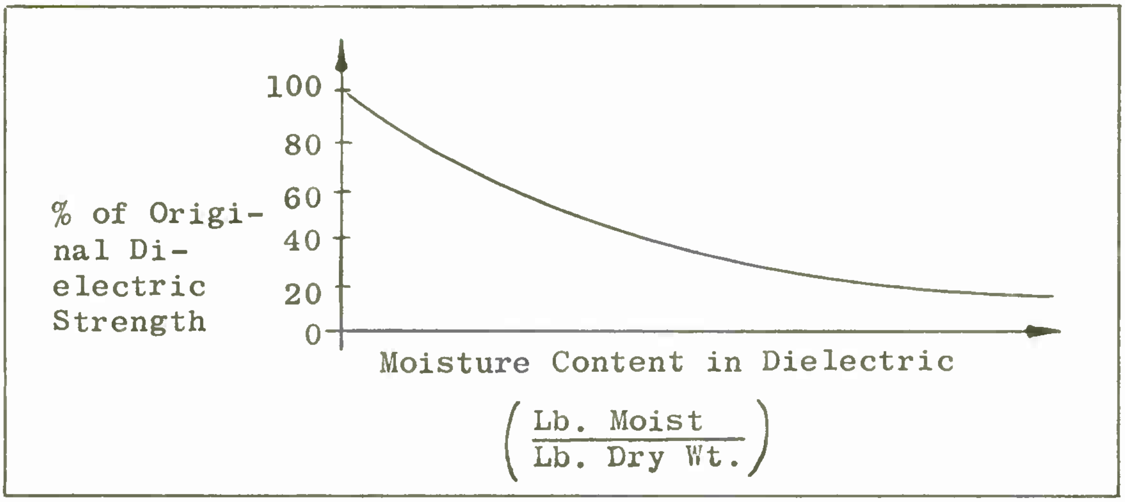

Figure 3-10. Plot of Dielectric Strength vs. Moisture Content

The dielectric strength printout is in tabular form or is a part of the curve which is significant for the range of values of moisture in arctic region.

(2) Moisture decreases insulation resistance of dielectric

$$R = R_o(1 - Ky)^4 \qquad 0 \leq y \leq 1 \qquad (49)$$

R_o = original insulation resistance

K = % of moisture saturation of dielectric

R = insulation resistance

Computer substitutes values and solves this equation.

(3) Power factor of capacitor increases with moisture.

$$P = P_0(1 + by + cy^2) \quad 0 \leq y \leq 1 \quad (50)$$

P_0 = original power factor at standard conditions

b and c = constants depending on dielectric

y = % of moisture saturation of dielectric

P = power factor.

Computer substitutes values and solves equation.

(4) Corrosion of container of metal clad capacitors increases sharply under high relative humidity. (See Figure 3-11.)

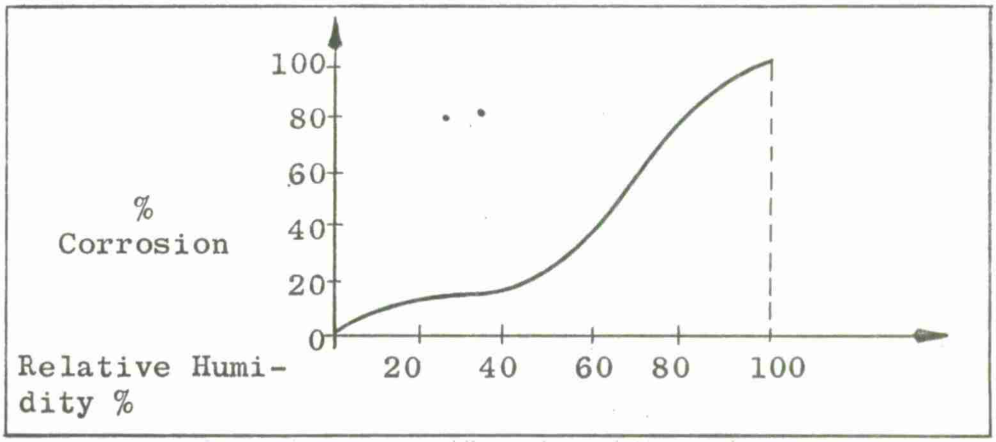

Figure 3-11. Plot of Corrosion vs. Relative Humidity

Computer shows region of interest on graph and obtains values of corrosion.

Electrolytic capacitor-Low temperature

(1) Reduction in effective capacitance at temperatures between $0^{o}C$ and $-40^{o}C$. The extent depends on electrolyte, type of foil, voltage rating and manufacturing techniques.

$$C_e = C(K_0 - K_1T^2 - K_2T^4) \quad T \leq 0^{o}C \quad (51)$$

C = capacitance

K_0, K_1, K_2 = constants depending on factors mentioned above

T = temperature in ^{o}C

C_e = effective capacitance.

Computer substitutes value and solves equation.

(2) Impedance of electrolytic units increases greatly at sub-zero temperatures.

(3) Dielectric breakdown voltage increases with low temperature (favorable effect).

(4) Direct current leakage value shows extreme decrease with low temperature (favorable effect).

D. Input test unit, climatic region, specific environmental factors and specific time of year. The computer selects ranges of values for the environmental factors and specific time of year within the regional location. These are used to predict effects on the test unit's properties depending on the data stored in the computer.

Example: Input: Electrolytic capacitor, Continental, Moisture Low temperatures, December.

Output: Output is similar to III-C except for equations and curves. Environmental factor ranges used for evaluation are for continental region for month of December. The ranges here are more specific than in III-C, as a specific time of year is used. This limits the ranges of temperature and moisture to only values occurring in the month of December.

E. Input test unit and specific environmental factors (natural or induced). Without any value ranges of environmental factors, the computer only predicts qualitative environmental effects on the test unit's properties depending on the data stored in the computer. In the case of graphs and equations the computer prints out the graph and unsolved equation.

Example: Input: Buna S rubber, Ozone, Temperature, Ozone-Stress (combined).

Output:

Buna S Rubber-Ozone

(1) Poor ozone resistance. Cracks quickly upon exposure to ozone.

Buna S Rubber-Temperature

(1) Good heat resistance to 212°F
(2) Maintains given degree of flexibility over wide temperature range.

Buna S Rubber-Ozone-Stress (combined)

(1) Rubber with ozonide formed in it may undergo a rearrangement resulting in chain scission. If the rubber is unstrained, the attack is only on the surface and is not serious. Strained rubbers however, on exposure to ozone, develop cracks. Two basic parameters govern the cracking process: (a) a critical stress needed for crack growth to begin and (b) a characteristic linear rate of crack growth once the linear stress is exceeded. (See Figure 3-12.)

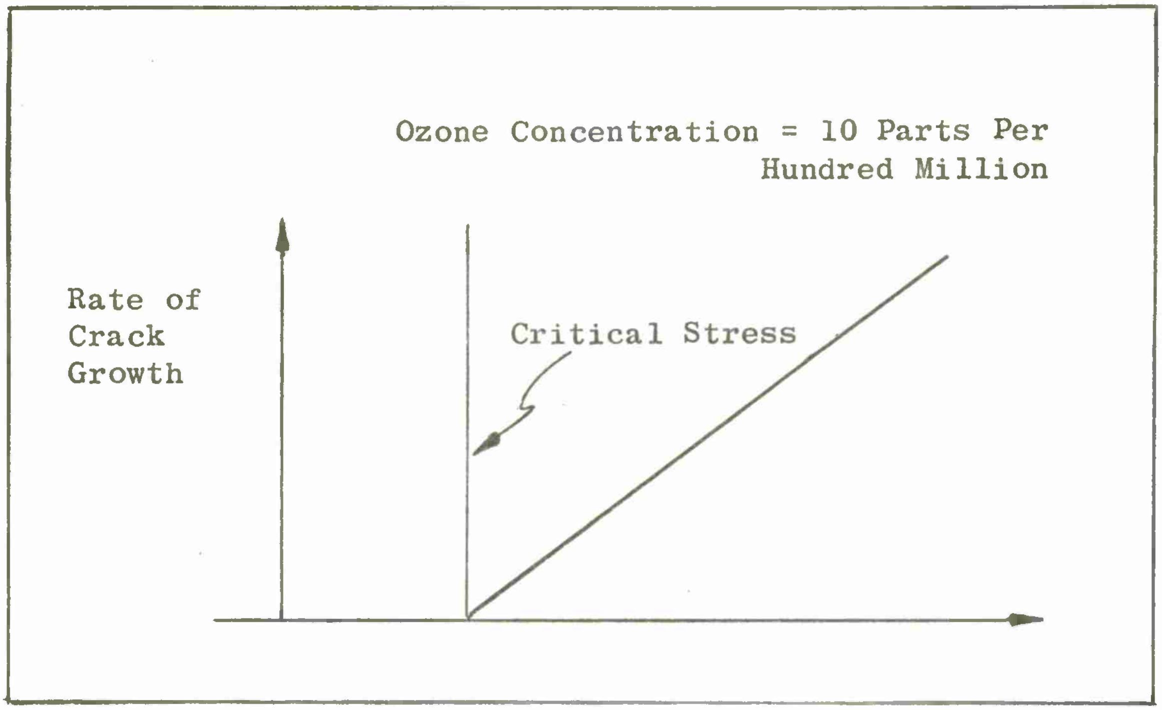

Figure 3-12. Plot of Rate of Crack Growth of Rubber Stress as a Function of Stress for Fixed Ozone Concentration

F. Input test unit, specific environmental factors (natural or induced) with ranges of their values. The computer uses these factors and values to predict environmental effects on the test unit's properties, depending on the data stored in the computer.

Example: Input: Electrolytic capacitor, 60 to 80% Relative humidity, Temperature $-20^{\circ}F$ to $20^{\circ}F$.

Output: Similar to III-C and III-D.

The difference here is that computer does not have to determine ranges of values for environmental factors since they are already given.

G. Input test unit with specific test unit properties, also environmental input as in either III-A, B, C, D, E or F. The engironmental effect predictions are given only on the mentioned test unit properties.

H. Input test unit with specific test properties and some ranges of values (not the ones subject of the query). Also environmental input as in III-A, B, C, D, E or F. The output is as in III-G, but here equations and graphs are solved utilizing test unit property ranges and values. These ranges will be used and the effects on the questioned parameters will be solved not only in terms of environments as in III-A through G, but also in terms of given property values.

System Information Types

1. Qualitative Statements - Straight printout.

2. Graphical Information - System should be able to:

   (a) print out graph (entire or sections).
   (b) given certain parameter(s), determine other(s) from graph.
   (c) determine ranges of interest from graph.

3. Tabular Information - System should be able to:

   (a) print out table (entire or sections).
   (b) determine values from table given needed properties.
   (c) interpolate values from table.

4. Equations - System should be able to:

   (a) print out equation.
   (b) evaluate equation in terms of as many of the variables whose values are given, i.e., in an equation with 3 dependent variables, if the values for 2 are given, it evaluates, leaving the other dependent variable in it, as:

$$y = f(u, v, w) = u + v + w = u + 5 + 10 \quad (52)$$

   if all three are known, it evaluates completely:

$$y = u + v + w = 15 + 5 + 10 = 30. \quad (53)$$

Other System Tasks

1. Where no information concerning a test unit exists in the system, a list of approximately 5 items from the next lower test unit assembly level is printed out, for further query about them as desired.

2. Request for information on a coated test unit will

require the use of several names. For example, if the test unit is an anodized aluminum part, the computer memory will predict environmental effects on anodized finishes and aluminum.

3. Where information on the specific environmental factor is not available in the computer, other environments most closely related to these will automatically be selected for study.

   Example: Environmental factors: Saigon, Rain. With no information contained on rain the computer would shift to humidity. Note: Had the regional location been New York, it would have included both snow and humidity as alternatives.

4. If no information is contained on a combined or sequential environmental factor, then prediction will be given of each of the environments singly (where contained).

5. If a geographical location is given, such as New Jersey, the regional location for this area will be stated, such as "temperate".

6. If a test unit is mentioned, the induced environments of interest (those which produce an effect on the test unit) will be stated.

7. The system is capable of processing raw data to determine analytical relationships which are stored for future predictions. This explained more thoroughly in Chapter VI,

The present system only utilizes deterministic analytical approaches to predict environmental effects on test units and their properties. A possible future aspect of the system would be the use of probability theory to predict failures of equipment exposed to environmental situations. The computer would be programmed to accept raw failure data on test units acted on by single, combined and sequential environmental factors. The computer would then be programmed to determine, from statistical operations, the corresponding probability distributions of time-to-failure (or number of failures). From these distributions, the computer can predict the time-to-failure for a given test unit in a given environmental situation. This type of model could be further sophisticated to predict the conditional probability of time-to-failure of a test unit, given that certain properties have a certain probability of exhibiting certain values due to environmental effects. Hence, it would use a stochastically modified version of the present model to obtain probability distributions of the property values of the test units in given environments. These distributions would then be used along with the conditional probability distributions of time-to-failure, given that the test unit properties have certain values, to predict test unit failures in environmental situations from their property excursions.

CHAPTER IV

ENVIRONMENTAL FACTOR SETS

This chapter is concerned with a procedure for classifying environmental situations in a concise uniform manner which is capable of identifying any of the possible environmental situations that may arise in a query to the prediction system.

The chapter presents the rationale of using an environmental factor set as a method of classifying environmental situations. It then establishes an environmental factor set which can be used to represent the complete envelope of possible environmental situations. The natural and induced environmental factors which comprise the set are presented and described. The next section deals with a description of the climate regions of the earth and a listing of the constituent environments of these regions, as well as their numerical ranges.

A description of a typical mission profile, as well as a listing of pertinent induced environments for the mission profile, then follows. An analysis of pairing environmental factors in confirmation and sequence is presented. Three categories of combination are considered:

Natural vs Natural
Induced vs Induced
Induced vs Natural

Finally the various possibilities of sequential environmental factors are analyzed. The effect of one environment on the other, as well as phasing of the environments, are considered.

Although the number of combined and sequential environmental combinations appears extremely voluminous at first glance, upon closer scrutinization it is seen that the multiplicity of environments may be reduced to a proportion which is tractable for computerization by considering only those combinations and sequences which are both feasible and applicable to the user's needs.

As a by-product, this chapter indicates areas where further research is necessary to determine the effects of certain environmental factors acting in combination or in sequence.

Rationale of Environmental Factor Set

A complex environmental situation may be decomposed analytically into its constituent environmental factors, be they combined or sequential. Only by such a decomposition can the environmental effects on a test unit be determined. For example, one of the environmental factors present in a combined environmental situation may have no effect on a test unit, while the other environmental factors do. If the combined environmental factors are not decomposed for individual analysis, one would not discover that this environmental factor has no effect on the test unit. Hence a prediction of another environmental situation, on the same test unit, containing the non-effecting environmental factor but none of the other original factors would incorrectly predict an effect.

With the rationale established for the need of an environmental factor decomposition, the question arises as to the optimum structuring of an environmental factor set.

A logical format to such a structure would begin with a bounded set of single environmental factors*, E_1, which when taken singly, combined, or sequentially, can express the entire gamut of possible environmental situations. That is, given any

*These are analogous to the SEF mentioned by Arnold in his report, "Synergistic Effects in Combined Environments Testing", November 1960, (Reference 2).

resultant environmental situation, E, using the single environmental factors, E_i, alone, in combination or in sequence, one may express that environmental situation. Mathematically this is expressed as:

$$E = \sum_{i=1}^{n} f(a_i)E_i + \sum_{j=1}^{m} \sum_{i=1}^{n} g_j(b_i)E_i$$

$$+ \sum_{j=1}^{k} \sum_{i=1}^{n} h_j(c_i)E_i \left[\mathcal{U}(t - t_i) - \mathcal{U}(t - t_{f_i})\right] . \qquad (54)$$

(See Figure 3-1 for an example of a generalized environmental situation.)

The first term, $\sum_{i=1}^{n} f(a_i)E_i$, contains all the <u>single</u> environmental factors in the resultant environmental situation. The $f(ai)$ are values for the <u>single</u> environmental factors (these are 0 where environmental factors are not present). The number of single environmental factors, E_i, in the environmental factor set is n.

The second term, $\sum_{j=1}^{m} \sum_{i=1}^{n} g_j(b_i)E_i$, contains all the <u>combinations</u> of environmental factors in the resultant environmental situation. $g_j(b_i)$ is the value of the i^{th} single environmental factor in the j^{th} combination of environmental factors. These are equal to zero when the environmental factor is not present in the combination and the environmental factor is omitted from the expression. n is again the number of single environmental factors, E_i, in the environmental factor set. m is the number of combinations of environmental factors, $\sum_{i=1}^{n} E_i$, in the combined environmental factor set.

The third term,

$$\sum_{j=1}^{k} \sum_{i=1}^{n} h_j(C_i)E_i \left[\mathcal{U}(t - t_i) - \mathcal{U}(t - t_{f_i})\right] .$$

contains all the sequences of environmental factors in the resultant environmental situation. $h_j(C_i)$ is the value of the i^{th} single environmental factor in the j^{th} sequence of environmental factors. These are equal to zero when the environmental factor is not present in the sequence and the environmental factor is omitted from the expression. $\left[\mu(t - t_i) - \mu(t - t_{f_i})\right]$ are step functions which start and cut off a single environmental factor of the sequence at the correct times. t_i is the start time for the i^{th} environmental factor and t_{f_i} is the cutoff time for the i^{th} environmental factor. n is again the number of single environmental factors, E_i, in the environmental factor set. k is the number of sequences of environmental factors. $\sum_{i=1}^{n} E_i \left[\mu(t - t_i) - \mu(t - t_{f_i})\right]$, in the sequential environmental factor set. For a more thorough discussion of sequential environmental factors, see page 4-22.

The usefulness of a bounded environmental factor set, whose members can be used to express any given environmental situation, is in the compactness it affords the system. Rather than having a category for every different environmental situation possible, categories are only set aside for each of the single, combined and sequential environmental facfactors in the environmental factor set. Of course, this compactness is only relative as there are still a voluminous number of categories of environmental factors for which combinations and sequences are accounted. To reduce this amount, only plausible combinations and sequences need be taken into account. As a realistic start, combinations and sequences need only be taken up to two or three at a time.

Presentation and Description of Environmental Factor Set

In attempting to establish an all-encompassing environmental factor set, several environmental sources were used. Among these were:

1. Mil Standard 810A (USAF). (Reference 10)
2. Arnold, Synergistic Effects in Combined Environments Testing. (Reference 2)

3. Mil Specification 5272(C). (Reference 11)
4. G. F. Arthur, An Investigation of the Concurrence of Environmental Elements. (Reference 3)
5. Boeing, Environmental Stresses Criteria Guide. (Reference 12)
6. Handbook of Environmental Engineering. (Reference 13)
7. APJ, Feasibility of Combined Environment Testing. (Reference 4)
8. APJ, Computer Prediction of Environmental Effects on USAF Materiel. (Reference 5)

The single environmental factors selected for the Environmental Factor set are listed in Figure 4-1.

Natural Environmental Factors	Induced Environmental Factors
1. Blowing Snow	1. Acceleration
2. Fungus	2. Acoustical Noise
3. Humidity	3. Chemical
4. Rain	4. Humidity
5. R.F. Interference (e.g. lightning)	5. Nuclear Radiation
	6. Ozone
6. Salt Fog	7. Pressure
7. Sand and Dust	8. R.F. Interference
8. Sunshine	9. Sand and Dust
9. Temperature	10. Shock
10. Wind	11. Temperature
11. Altitude	12. Vibration

Figure 4-1. Table of Single Environmental Factors

It should be noted that this list is directed only to environmental situations which affect Army materiel. Hence, space environments such as Van Allen radiation and extraterrestrial vacuum are not included. Furthermore certain environmental factors not listed above can be described by using one or more of the above categories. For example, an altitude environment is described by the environmental factors temperature, pressure and humidity.

Also to be noted is the fact that some of the above environmental factors comprise subcategories of environmental factors, as explained in the following discussion.

The units of measurement for the environmental factors are listed in Figure 4-2. These dimensional units may be utilized readily in quantitative environmental-effects analysis.

Environmental Factor	Units
Blowing Snow	Inches/Month
Fungus	Fungus density measure
Humidity	% Relative Humidity
Rain	Inches/Month
R.F. Interference (Lightning)	Volts
Salt Fog	% Salt Solution
Sand and Dust	Oz./Ft.^{3}
Sunshine	Watts/Ft.^{2} and Angstroms
Temperature	^oF.
Wind	Miles/Hour
Acceleration	G Load
Acoustical Noise	db.
Chemical	Chemical product measure
Nuclear Radiation	RADS for Gamma neut/cm^2 sec for fast neutr.
Ozone	PPHM (parts per hundred million)
Pressure	PSIA for Higher Pressures TORRS for Vacuum
Shock	G Load
Vibration	CPS and Amplitude

Figure 4-2. Table of Units of Single Environmental Factors

The environmental factor termed "Chemical" includes such items as gases, chemical fumes, atmospheric contaminants, acids. alkalies, fuels and lubricants. Note that ozone and salt fog are actually subcategories of the "Chemical" environmental factor. Due to their importance, however, they are considered as separate environmental factors.

The environmental factor fungus likewise includes the subfactors fungi, bacteria, algae, insects, marine organisms and rodents. The reason for calling the environmental factor fungus is that this category is the most prevalent in deterioration problems of the subfactors listed above.

Operational environmental factors such as voltage, current and mechanical loads have been eliminated. These factors differ from the others selected in that they are deliberately introduced as primary functions of the test units, and in this sense are not considered basically detrimental to test unit operation. The listed factors are usually detrimental to the operation of the test unit and their mitigation is desirable.

Although the environmental factors "rain" and "blowing snow" are subcategories of humidity, as are hail, sleet and frost, their presence and effects are considered more prevalent and so only blowing snow and rain are specifically distinguished from humidity.

The environmental factors temperature humidity, sand and dust, and R.F. interference are listed as both natural and induced environments, since they may occur in either circumstance.

Natural Environment Description of Climatic Regions

The various natural environmental factors occur in differing degrees in different parts of the world. To distinguish possible environmental situations occurring in different regions, the world may be considered as a set of climatic regions with prevalent environmental factors and a range of average values for these regions listed.

The following climatic regions describe the main environmental divisions of the world.

1. Ice Cap,
2. Arctic,
3. Maritime,
4. Continental,
5. Desert and Steppe,
6. Tropical,
7. Highland.

Figure 4-3 illustrates these regions on a map of the world.

The following table gives the environmental factors and ranges of average values for these climatic regions where known. (See Figure 4-4.)

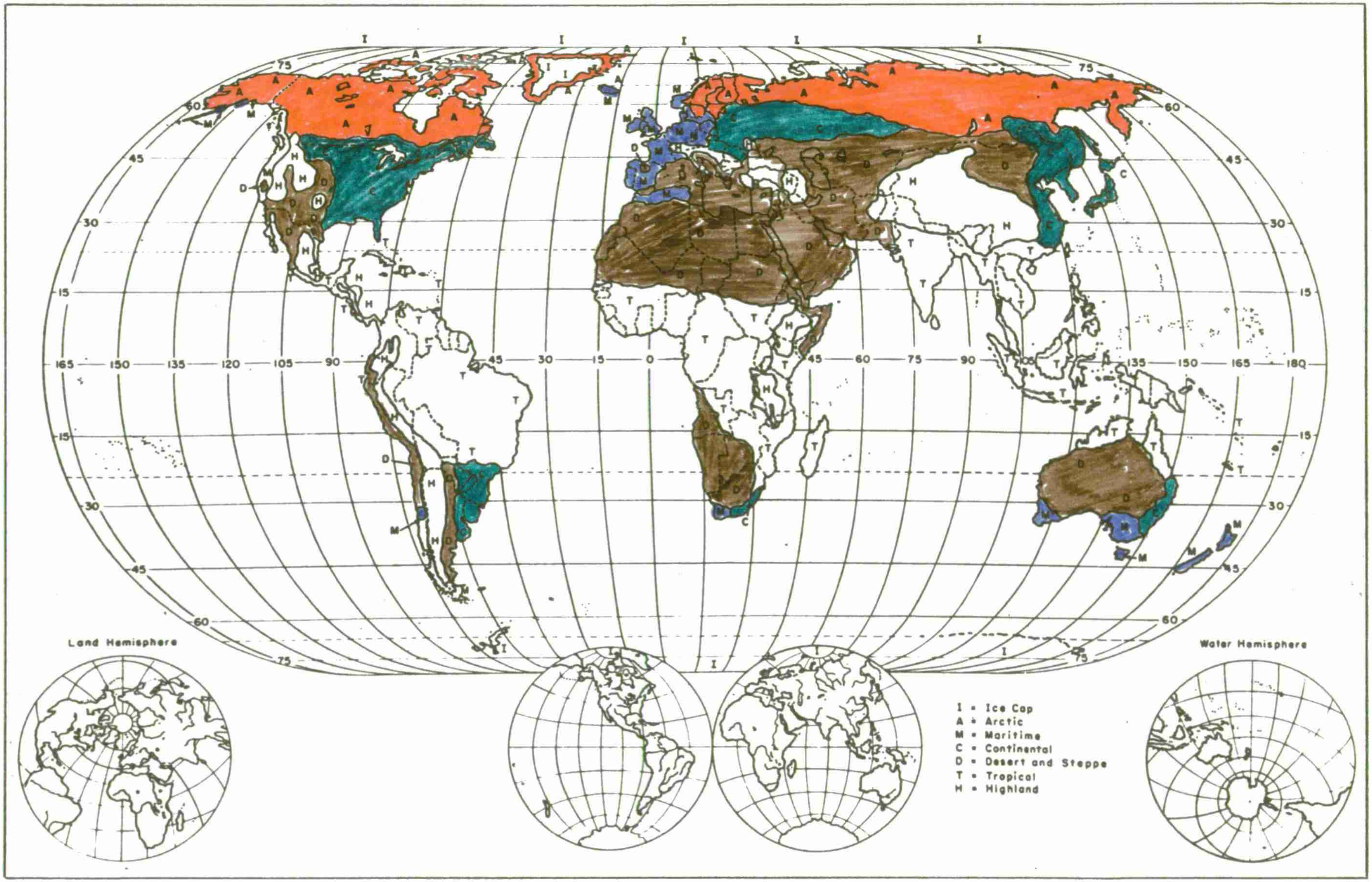

Figure 4-3. Map of World, Classifying Climatic Region (Reference 4)

NORTHERN ICE CAP	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Temperature (°F)	-16.2	-17	-14.8	.4	19.6	39.7	40	38.6	31.6	16.6	-.3	-11
Driven Snow (In/Mo)	1.35	1.89	1.55	1.08	1.55	3.9	6.2	5.1	4.24	5.22	3.8	2.43
Winds (MPH) 1/	10 to 20	10 to 20	10 to 20	10 to 30	10 to 30	10 to 30	10 to 30	10 to 30	10 to 30	10 to 20	10 to 20	10 to 20
ARCTIC	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**
Temperature (°F)	-11.2 to 27.3	-1.6 to 27.9	9.5 to 30.6	29.2 to 38.3	45.4 to 46.9	53.6 to 58.3	54.2 to 60.1	53.6 to 55.4	43.6 to 48.9	26.7 to 40.5	4.1 to 33.1	-7.1 to .27.7
Driven Snow (In/Mo)	8.3 to 30.9	4.42 to 25.4	6.3 to 20.2	0 to 2.52	0	0	0	0	0	0 to 7.65	0 to 6.48	5.68 to 23.1
Winds (MPH)	10 to 30	10 to 30	10 to 30	10 to 20	10 to 20	10 to 20	10 to 20	10 to 20	10 to 20	10 to 30	10 to 30	10 to 30
MARITIME	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**
Relative Humidity(%)	60 to 87	61 to 86	65 to 82	72 to 86	71 to 89	68 to 93	67 to 91	68 to 89	68 to 83	66 to 89	63 to 91	60 to 90
Sunshine												
Salt Spray												
Temperature	34.2 to 69.6	34.3 to 70.3	36 to 68.4	42.3 to 65.9	48 to 62.3	43.8 to 62.7	42.4 to 67.6	44 to 67.3	47.7 to 62.5	45.3to 62.4	39.2 to 65.3	35.6 to 68.6
Fungus												

1/ Approximation
2/ Excerpted from Reference 31 and modified to conform with format developed in Reference 4.

Table 4-4. Calendar Variation of Environmental Factor Values in Various Climatic Regions 2/

CONTINENTAL	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Temperature (°F)	-4.2 to 33	.7 to 38.5	16.1 to 47.6	34 to 56.2	44 to 66.2	50.2 to 75.3	58 to 79.8	59.5 to 77.9	51.4 to 70.8	38.1to 59.5	19.2to 45.7	1 to 36
Relative Humidity(%)	66 to 89	64 to 87	60 to 88	52 to 83	52 to 84	53 to 90	55 to 92	57 to 92	60 to 88	64 to 90	65 to 91	69 to 90
Sand and Dust												
Driven Snow (In/Mo)	0 to 19.7	0 to 18.7	0 to 17.3	0	0	0	0	0	0	0	0 to 6.15	0 to 14.2
DESERT & STEPPE	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**
Temperature (°F)	19.2 to 85.9	22.8 to 85.4	32.5to 87.4	43.8 to 88.4	52 to 92.9	54.8 to 93	53.2 to 94	54.1to 93	54.4to 90	45.6 to 89.6	32.8to 84.6	24.6 to 85.9
Relative Humidity(%)	30 to 89	23 to 92	16 to 91	15 to 87	19 to 84	17 to 85	17 to 86	15 to 84	17 to 86	23 to 85	29 to 86	31 to 89
Sand and Dust												
Sunshine												
Driven Snow (In/Mo)	0 to 2.7	0 to 2.0	0	0	0	0	0	0	0	0	0	0 to 2.52
TROPICAL	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**
Relative Humidity(%)	23 to 93	20 to 93	22 to 98	32 to 91	48 to 89	54 to 91	51 to 92	53 to 93	57 to 92	48 to 90	26 to 89	20 to 90
Rain (In/Mo)	0 to 19.0	0 to 16.0	0 to 18.1	.03 to 16.73	.20 to 16.57	.16 to 46.94	.08 to 54.80	.12 to 45.19	.08 to 22.57	.53 to 19.49	0 to 21.02	.01 to 18.90
Salt Spray												
Fungus												
Sand and Dust												

1/ Excerpted from Reference 31 and modified to conform with format developed in Reference 4.

Table 4-4. Calendar Variations of Environmental Factor Values in Various Climatic Regions (Continued)1/

The ice cap climatic region includes the poles, polar islands and most of Greenland (except coastal regions). The prevalent environmental factor in this region is extremely cold temperature. The warmest temperatures for this area are well below freezing. Other environmental factors in this region include high winds, and blowing snow.

The arctic climatic region includes Alaska, Northern Canada, the coast of Greenland, most of Iceland, most of the Scandinavian countries and the area east of Leningrad bounded by Lake Baikal, the Sea of Okhotsk and the Kamchatka Peninsula. The prevalent environmental factors in this area include extremely low temperatures, blowing snow and high winds in the cold seasons.

The maritime climatic region includes the West Coast of North America from Juneau south to Humboldt Bay in northern California; the coastal sections of California from San Francisco to San Diego; the coastline of Chile from Tacopilla south including Cape Horn and the Falklands; the southern third of Ireland; the British Isles; the west coast of Norway; southern Norway and Sweden; the region surrounded by Gottland (in the Baltic), Danzig, Cracow, Breslau, Leipzig, the Alps and the Rhone Valley; the Mediterranean coastline; the Black Sea coastline of Northern Turkey and southern Crimea; the area around Capetown in South Africa; the Australian coastline from Perth to the Esperance area and from the Eyre Peninsula to Gippsland; and Tasmania and New Zealand. The environmental factors prevalent in this climatic region are humidity, sunshine, salt spray, temperature and fungus.

The continental climatic region includes the continental United States and southern Canada from the Rockies to the Atlantic; the Buenos Aires area in South America; the southeast tip of Africa; the greater part of the Balkans, eastern Poland, northern Ukraine, and a narrow strip extending east almost to Lake Baikal; southeast Siberia; and eastern China. The prevalent environmental factors in this climatic region are temperature, humidity, sand and dust, and driven snow.

The desert and steppe climatic region includes most of the western United States and Lower California (Mexico); Patagonia in South America; Sahara region and southwest Africa; the Arabian Peninsula; the Persian Gulf area; Anatolia; southern Ukraine; Dzungaria; Sinkiang; Mongolia; and most of Australia. The prevalent environmental factors in this climatic region are temperature, humidity, sand and dust, sunshine and driven snow.

The tropical climatic region includes parts of Mexico; the southern tip of Florida; the West Indies; most of Central America; all of South America north of the Tropic of Capricorn except the Andes Mountains and the central west coast; all of Africa from 10° North Latitude southward to approximately 8° South Latitude on the west coast diagonally southeast to 25° South Latitude on the east coast except two upland areas; most of India and Pakistan; southeastern Asia; the Malay Archipelago; the northern coast of Australia; the East Indies and other South Pacific islands. The principal environmental factors in this climatic region are humidity, rain, salt spray, fungus, sand and dust.

The highland climatic region includes the Rocky Mountains and the Sierra Nevada range of the Western United States, the mountainous areas of Mexico and Central America, the Andes Mountains in South America; the European Alps; the mountains of Ethiopia; the Caucasian Mountains and the Tibetan Plateau. The principal environmental factors of this climatic region are pressures which are comparatively (lower than sea level) temperature, snow and winds.

Induced Environment Description Pertinent to Mission Profile

The various induced environmental factors of the environmental factor set occur as by-products of test unit operation. An environmental factor breakdown for the induced environmental factors, similar to the climatic region breakdown for natural environmental factors, derives from analysis of specific test unit mission profiles to be considered. That is, for a given mission profile, a test unit will encounter certain induced environmental factors. Induced environmental factors applied to mission profile description include certain environmental factors which by definition are "natural", but which impinge on the mission profile through operation of the test unit.

A typical mission profile breakdown, in which a representative test unit might encounter a spectrum of induced environmental factors during various discrete operating modes, is shown in Figure 4-5. The test unit in this case is a complete aircraft system, a compound helicopter incorporating an advanced, multi-fire-power capability. The mission is a guerilla warfare sortie in a region such as Vietnam.

	Mission Operating Modes					
	Take-off	Cruise	Hover	Fire	Dash	Land
Induced Environmental Factors	Hi-Temp. Sand and Dust Humidity Vibration	Low-Temp. R.F. Interfer. Ozone Vibration	Chem. Fume Chem. Vapor Hi-Temp. Vibration	Shock Blast Press. Explos. Press. Acoustic Vibr.	Condensation Low-Temp. Vibration	Hi-Temp. Sand Dust Humidity Vibration Shock

Figure 4-5. Mission - Guerilla Warfare Helicopter Sortie Vietnam.

It should be noted that certain of the induced environmental factors shown, such as chemical fumes, are not given in the complete table of factors of section B, but may be considered as subfactors of the prime (i.e., chemical).

<u>Pairing of Environmental Factors in Combination and Sequence</u>

If each of the single environmental factors listed in the previous section are considered in determining the possible number of sequences and combinations, the following would result. There are 11 natural environmental factors and 12 induced environmental factors for a total of 23 environmental factors to be considered.

Since combined environmental factors act simultaneously, the order of occurrence is unimportant so that the number of possible combined environmental factors would be:

$$\sum_{r=2}^{23} {}_{n}C_{r} = \sum_{r=2}^{23} \frac{23!}{(23 - r)!\, r!} = 8,388,584 \qquad (55)$$

where n = number of environmental factors = 23
r = number of environmental factors to be considered at one time.

In considering sequential environmental factors, the order of occurrence must be considered so that the number of possible sequential environmental factors would be:

$$\sum_{r=2}^{23} {}_{n}P_{r} = \sum_{r=2}^{23} \frac{23!}{(23 - r)!} > 9 \times 10^{22}. \qquad (56)$$

Obviously, the numbers of combinations and sequences to be considered are too large to be feasible in an environmental prediction system. As a primary approximation, a realistic approach is to consider combinations and sequences taken only two at a time. This approximation is not unreasonable, since it is unlikely that more than three or four interacting environmental factors will occur in a given environmental situation.

The number of possible combined environmental factors, taken two at a time, for the 23 environmental factors in the environmental factor set is determined to be:

$$ {}_{23}C_{2} = \frac{23!}{21!2!} = 253 \qquad (57)$$

The number of possible sequential environmental factors, taken two at a time, for the 23 environmental factors in the environmental factor set is determined to be:

$$_{23}P_2 = \frac{23!}{20!} = 506. \tag{58}$$

A further way of extending the treatment of combined and sequential environmental factors is to consider the effects of sequences of combined environments. It is evident that sequences of combinations have the effect of spectacularly increasing the already unacceptably large number. One way of approaching this case which may be feasible is to consider a simple sequence consisting of two environment combinations, each comprising two single environments, as follows:

This can be treated by first considering the effects of each of the combined environments, and then considering the effects resulting from the sequence of these combined environments.

Further, the number of combined and sequential environmental factors can be significantly reduced from the above numbers by considering the fact that certain combinations and sequences do not occur by nature, or are inconsequential. With this consideration a tractable computer storage facility and prediction utilization technique can be developed.

To determine which environmental factors actually would occur in combination or in sequence, the natural and induced environmental factors were matched against each other and themselves so that improbable combinations could be eliminated. This matching technique produced three matrices of possible environmental factor combinations or sequences taken two at a time. They are:

1. Natural vs. Natural
   Environmental Factors
2. Induced vs. Induced
   Environmental Factors
3. Induced vs. Natural
   Environmental Factors.

	Blowing Snow	Fungus	Humidity	Rain	R.F. Interference (Lightning)	Salt Fog	Sand and Dust	Sunshine	Temperature	Wind
Blowing Snow			A,C, D	C			C,D		A,C, I	A,I
Fungus			C,M, T			M,T	C,D	M	C,M	T
Humidity	A,C, D	C,M, T		C,M, T	C,M, T	M,T	C,D, T	D,M	A,C, D,M	A
Rain	C	C,M, T	C,M, T		C,M, T	M,T	C,T			C,T
R.F. Interference (Lightning)			C,M, T	C,M, T		M,T				C,T
Salt Fog		M,T	M,T	M,T	M,T		T	M	M	T
Sand and Dust	C,D	C,D	C,D T	C,T		T		D	C,D	C,D
Sunshine		M	D,M			M	D		D,M	D
Temperature	A,C I	C,M	A,C, D,M			M	C,D	D,M		A,I
Wind	A,I	T	A	C,T	C,T	T	C,D	D	A,I	

Figure 4-6a. Combined and Sequential Environmental Factors - Natural vs. Natural

The matrices depicting combinations or sequences of natural vs. natural and natural vs. induced were studied further. For each occurring combination or sequence, the climatic regions where the occurring natural environmental factors could apply were noted in the specific matrix cells.

The matrices are shown in Figures 4-6, -7 and -8.

From the three matrices, it is seen that there are 35 combined and 70 sequential natural vs. natural environmental factors for possible consideration. There are 44 combined and 88 sequential induced vs. induced possibilities, and 78 combined and 156 sequential induced vs. natural environmental fac-

C O D E

Insertion of a climatic region in the matrix indicates a significant effect occurrence of the two intersecting natural environmental factors (combined or sequential) in that region.

Blank space indicates no significant effect occurrence.

Climatic Region Code

A = ARCTIC

C = CONTINENTAL

D = DESERT AND STEPPE

I = ICE CAP

M = MARITIME

T = TROPICAL

Figure 4-6b. Combined and Sequential Environmental Factors - Natural vs. Natural

	Acceleration	Acoustical Noise	Chemical	Humidity	Nuclear Radiation	Ozone	Pressure	R.F. Interference	Sand and Dust	Shock	Temperature	Vibration
Acceleration							X		X	X	X	X
Acoustical Noise				X			X	X			X	Δ
Chemical				Δ	Δ	Δ					X	
Humidity		X	Δ		Δ	X	X	X		Δ	X	Δ
Nuclear Radiation			Δ	Δ		Δ	Δ	Δ	Δ	Δ	Δ	Δ
Ozone			Δ	X	Δ		X		Δ	X	X	X
Pressure	X	X	X	X	Δ	X			Δ	X	X	X
R.F. Interference		X			Δ							
Sand and Dust	X			X	Δ	Δ	Δ			Δ	Δ, X	Δ
Shock	X			Δ	Δ	X	X		Δ		X	X
Temperature	X	X	X	X	Δ	X	X		Δ, X	X		X
Vibration	X	Δ		Δ	Δ	X	X		Δ	X	X	

Figure 4-7a. Combined and Sequential Environmental Factors - Induced vs. Induced

C O D E

Insertion of an "X" in the matrix indicates a significant effect occurrence of the two induced environmental factors (combined or sequential).

Insertion of a "△" indicates the necessity for further research.

Blank space indicates no significant effect occurrence.

Figure 4-7b. Combined and Sequential Environmental Factors - Induced vs. Induced

Induced Environmental Factors / Natural Environmental Factors	Acceleration	Acoustical Noise	Chemical	Humidity	Nuclear Radiation	Ozone	Pressure	R.F. Interference	Sand and Dust	Shock	Temperature	Vibration
Blowing Snow		A,C,D	A,C,D		△	A,C,D	A,C,D		A,C,D		A,C,D	A,C,D
		I,T	I,T			I,T	I,T		I,T		I,T	I,T
Fungus		C,M	C,M				C,M		C,M	C,M	C,M	C,M
		T	T				T		T	T	T	T
Humidity		A,C,D	A,C,D	A,C,D	△	A,C,D			A,C,D		A,C,D	A,C,D
		M,T	M,T	M,T		M,T			M,T		M,T	M,T
Rain		C,M	C,M		△	C,M	C,M		C,M		C,M	C,M
		T	T			T	T		T		T	T
RF Interference (Lightning)	C,M	C,M			△	C,M	C,M	C,M		C,M		C,M
	T	T				T	T	T		T		T
Salt Fog			M,T		△	M,T			M,T		M,T	M,T
Sand and Dust	C,D		C,D	C,D	△	C,D	C,D		C,D		C,D	C,D
	T		T	T		T	T		T		T	T
Sunshine			D,M	D,M	△	D,M			D,M		D,M	D,M
Temperature	A, C, D		A, C,D	A, C,D	△	A, C,D	A, C,D		A, C,D	A, C,D	A, C,D	A, C,D
	I,M		I,M	I,M		I,M	I,M		I,M	I,M	I,M	I,M
Wind	A, C, D				△	A, C,D	A, C,D		A, C,D	A, C,D		A, C,D
	I,T					I,T	I,T		I,T	I,T		I,T

Figure 4-8a. Combined and Sequential Environmental Factors Induced Vs. Natural

CODE

Insertion of a climatic region in the matrix indicates a significant effect occurrence of the two intersecting environmental factors (combined or sequential) in that region.

Insertion of a "△" indicates the necessity for further research.

Blank space indicates no significant effect occurrence.

Climatic Region Code

A = ARCTIC

C = CONTINENTAL

D = DESERT AND STEPPE

I = ICE CAP

M = MARITIME

T = TROPICAL

Figure 4-8b. Combined and Sequential Environmental Factors Induced Vs. Natural tor possibilities. Totaling these cases, there are 157 combined and 314 sequential environmental factor possibilities for consideration. Of course, this number is approximate; but it gives a good range on the size of the environmental factor set necessary for an environmental effects prediction system. Although large this number indeed brings the problem of the number of environmental combinations and sequences within the realm of computer techniques. Of course the large number of terms requires an efficient storage scheme capable of handling the large volume of information required by the system.

Sequential Environmental Factors

The term sequential environmental factor mentioned on pages 4-3 and 4-4 refers to a sequencing of two or more single or combined environmental factors. The simplest form of sequential environmental factor consists of two single environmental factors acting as follows: One environmental factor, X, acts for a given time; upon its termination, the second environmental factor, Y, acts. On a time scale, this case would appear as shown in Figure 4-9.

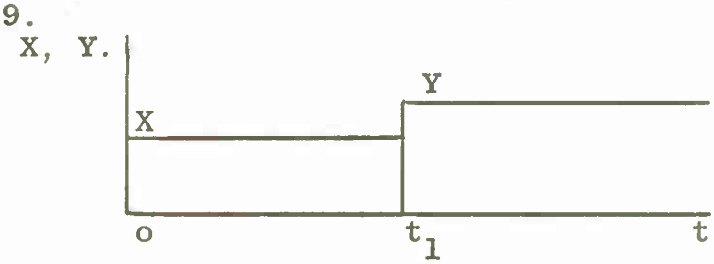

Figure 4-9. Simple sequential case

There are many modifications of this simple case to yield more complex sequential environmental situations.

One modification has environmental factor Y beginning while environmental factor X is still in existence. After an interval of X and Y acting together, X turns off. Pictorially this case appears as shown in Figure 4-10.

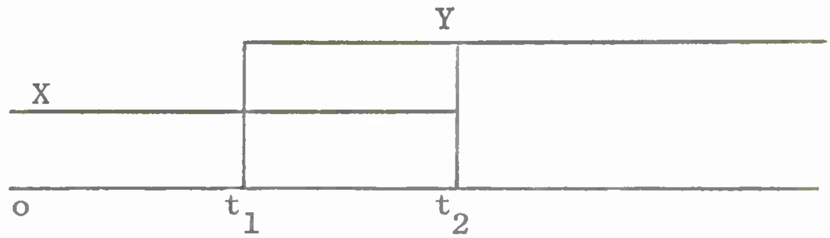

Figure 4-10. Overlap sequential combined case

Another modification has a delay interval between the time X ends and Y begins. This appears as shown in Figure 4-11.

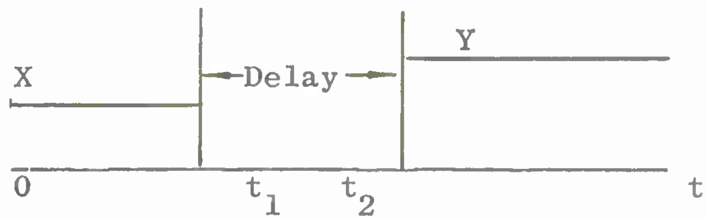

Figure 4-11. Delayed sequential case

Other modifications include more than two single environmental factors, sequenced in different combinations of the three aforementioned cases.

Considering two single environmental factors as in case 1 (no overlap), several possible results of the sequencing may occur. Let Z be defined as the condition that environmental factor X causes a change in the effect of environmental factor Y.

The first possibility is $Z = 0$. That is environmental factor X has no influence on the effect of environmental factor Y. In this instance the effect of Y when it follows X is exactly the same as if Y acted entirely alone. An example of this would be sand and dust accumulating on an exposed part followed by lightning. Obviously the sand and dust will not change the effect of the lightning.

The next possibility is $Z = f(t)$. That is, the change in the effect of Y due to the pre-occurrence of X is determined by only the intensity level of X. An example of this phenomenon is a shock causing a hairline crack in a seal, followed by occurrence of humidity. Assume that the crack does not change in size once it occurs, and that the size of the crack depends on the g load of the shock, and that the seal is so constructed that any amount of g load will cause it to crack some amount. Now the amount of g load determines the size of the crack, which determines how much moisture from the humidity will seep through the crack into the seal and hence affect the part in question. In this case the duration of the first environmental factor, shock, had no influence on the effect of the second environmental factor, humidity; only the magnitude of shock had an influence on the effect of humidity.

A third possibility is $Z = f(X, t)$. That is the change in the effect of Y, due to the pre-occurrence of X, is determined by both the intensity level of X and the duration time in which X was applied. An example of this is radiation followed by vibration. The radiation, arriving at a certain rate causes embrittlement of a test unit which comes apart when set in vibration. In this case the effect of vibration is influenced by both the rate of radiation applied and the duration of its application.

A modification of this case is $Z = f(X, t, t_d)$. That is the change in the effect of Y due to the pre-occurrence of X is determined by the intensity level of X; the duration time in which X was applied, t, and a delay time, td. An example of this is the heating of a metal which causes a permanent change in the metal's tensile strength after it cools off, followed by vibration (assuming that vibration has no effect on the metal at its original tensile strength X or while it is at a temperature above a certain level.) When the applied heat is stopped, vibration is applied. No immediate effect occurs. When the temperature of the metal cools off to the point where the tensile strength changes, the metal cracks. Now the amount of cracking is a function of the temperature to which the metal was raised, the time in which heat was applied to the metal, and the time in which the metal cools off.

Another possibility is $Z = f(X, \int x\,dt)$. That is, the effect of Y due to a pre-occurrence of X is determined by the intensity level of X and the cumulative effect of X acting through a given time. An example of this is ozone acting on a piece of rubber, followed by repeated shocks (pounding of the rubber by a constant g load in such a way so as to stretch it). The ozone chemically combines with the rubber to form ozonide. The ozonide breaks easily under stress to form a crack. The effect of shock depends on the quantity of ozone to which the rubber was exposed, and the cumulative amount of ozonide layer formed.

In still another possibility, $Z = 0$ for $X < K$. That is, the pre-occurrence of X influences the effect of Y only if X was at a level above some threshold, K; otherwise X has no influence on the effect of Y. An example of this is shock (dropping of a part) followed by vibration of the part. It is assumed that vibration has no effect on the part originally or until its properties are changed to some threshold value. Now unless the shock was sufficient to change the strength of the part past a threshold value, the vibration will not affect it. If the shock did sufficiently change the part's strength then vibration will cause it to fall apart. Hence the effect of vibration is dependent on the shock being above a given threshold level.

The sequential environmental case involving overlap illustrated in Figure 4-10, can be analyzed as follows: The period when X is acting alone is treated as a single environmental factor situation. The period of X and Y overlapping is treated as a sequential environmental factor situation, X followed in sequence by the combined environmental factors X and Y. The period when Y is acting alone is treated as a triple sequence of environmental factor X, followed by combined environmental factors X and Y, followed by environmental factor Y.

The sequential environmental situation, illustrated in Figure 4-11, in which there is a delay between the termination of X and the application of Y, involved the recovery of the test unit from exposure to X.

As can be seen, time is an essential factor in the analysis of sequential environmental situations. For this reason, sequential environmental factors must be classified not only by their contributing segments of environmental factors, but also by the duration of these factors and, in cases where recovery time applies, the delay time between environmental factor applications.

CHAPTER V

TEST UNITS

This chapter is concerned with a procedure for classifying test units in an organzied manner to facilitate efficient utilization by the computer.

The chapter presents a hierarchy of test unit levels identified at level of assembly based on item usage. This is followed with examples. The advantages of a test unit hierarchy for efficient system operation are then discussed.

The role of test unit properties in effects prediction follows. The fact is brought out that quantitative effects on the test unit must be measured by variation in the test unit's properties. Examples of test unit properties for the various levels of the test unit hierarchy, giving units of measurement, are listed. Special test unit categories such as coatings and protective devices, and how they are handled by the system, are discussed.

Organization on Hierarchy Basis

An important aspect of a computerized environmental effects prediction system is an organized hierarchy of test unit levels into which the system's test units can be categorized. Controversy may exist over the form of such a hierarchy and the classification of test units into the various categories. However, if an organized categorization is established for the prediction system and adhered to by all users, then the particular form of such a classification is not critcal, since the main reason for the test unit categorization is to facilitate efficient utilization by the computer.

The following hierarchy is identified at level-of-assembly based on item usage.

I. Materials: Basic structural element of test unit. Basic construction item for test units.

II. Parts: Basic fabricated element of test unit capable of being used without further processing; cannot be dismantled without destruction.

III. Components: Combination of parts, does not perform function in isolated state.

IV. Assemblies: Combination of parts and/or components which can perform a limited function in an isolated state.

V. Systems: Combination of parts, components and/or assemblies which perform a complete function. 1/

The following is a list of test units, categorized by the above levels, which are representative of some of the items to be considered. The list is designed to be responsive directly to Army equipment.

Representative Test Unit Taxonomy

I. Materials

A. Metals and Alloys

Examples:

1. Copper
2. Iron
3. Steel

1/ Man-machine systems are relevant from the induced environment point of view. Man creates potentially synergistic phenomena. Behavior of a test unit depends on the usage to which it is placed and the skills of the people using it. Environmental effects on the man also determine performance of the system.

B. Plastics and Elastomers
   Examples:
   1. Plastic
   2. Rubber
      a. Natural
      b. Synthetic

C. Abrasive Materials
   Examples:
   1. Glass
   2. Ceramics and Porcelains

D. Petroleum Products
   Examples:
   1. Oils
   2. Greases
   3. Fuels
   4. Hydraulic fluids

E. Fibrous Materials
   Examples:
   1. Woods
      a. Hardwoods
      b. Softwoods
   2. Paper
   3. Textiles and Cordage
      a. Cotton
      b. Wool
      c. Synthetic textile

F. Leathers

G. Coatings
   Examples:
   1. Paints
   2. Preservatives
   3. Sealers
   4. Metal coatings

II. Parts

A. Mechanical
Examples:
1. Spring
2. Screw
3. O-ring

B. Electrical
Examples:
1. Capacitor
2. Resistor
3. Transister

III. Components

A. Mechanical
Examples:
1. Bearing
2. Valve
3. Filter (Hydraulic)

B. Electrical
Examples:
1. Battery
2. Filter (Electrical)
3. Transformer

C. Electromechanical
Examples:
1. Switch
2. Connector
3. Relay

IV. Assemblies

A. Mechanical
Examples:
1. Pump
2. Transmission
3. Compressor

B. Electrical
Examples:
1. Oscilloscope
2. Receiver
3. Transmitter

C. Electromechanical
Examples:
1. Motor
2. Generator
3. Electrical measuring instruments

V. Systems

A. Radar system

B. Tank

C. Hawk missile

etc.

etc.

So that system users utilize the correct nomenclature, a detailed cross-referencing index must be established. This listing should be dynamic, reflecting changes and additions to the computer memory. Within this index must be contained the computer terminology for a test unit, cross--referenced to the various trade names and other names by which the product is also known. An example of this is given below for rubbers.

TYPES OF RUBBER

1. Natural Rubber (Natural Polyisoprene, NR)

2. Synthetic Polyisoprene (IR)
Trade names

Coral - Firestone Rubber and Latex Co.
DPR - DPR, Inc.

Natsyn - Goodyear Tire & Rubber Co.
Trans-Pip - Polymer Corp. Ltd.
Shell Isoprine - Shell Chem. Co.

3. Styrene Butadiene (SBR, Buna-S, Buna-S.S., GR-S, Butaprene S, Chemigum, Hycar OS, Nubun)
Trade Names

Ameripol - Goodrich-Gulf Chem. Inc.
ASRC Polyners - Amer. Synth. Rubber Corp.
Baytown Masterbaches - United Carbon Co.
Carbomix - Copolymer Rubber & Chem. Co.
Copo - CoPolmer Rubber & Chemical Co.
Duradene - Firestone Synth. Rubber & Latex Co.
FR-S - Firestone Rubber Co.
Flosbrene - Amer. Synth. Rubber Co.
Gen Flow - General Tire & Rubber Co.
Gentro - General Tire & Rubber Co.
Jetron - General Tire & Rubber Co.
Hycar - B. F. Goodrich Chem. Co.
Naugapol - U. S. Rubber Co.
Naugatex - U. S. Rubber Co.
Plioflex - Goodyear Tire & Rubber Co.
Philprene - Phillips Petroleum Co.
Polysar Kryflex - Polymer Corp. Ltd.
Polysar S - Polymer Corp. Ltd.
S Polymers - Shell Chemical Co.
Solprene X - Phillips-Petrol. Co.
Synpol - Texas-US Chemical Co.
Tylac - International Latex Corp.

4. Stereo SBR

5. Butyl (IIR, Isobutylene Isoprene, G R-1, Isobutylene Diolefin)
Trade Names

Bucar Butyl - Vellumoid Co.
Enjay Butyl - Enjay Chemical Co.

Petro Tex Butyl - Petro Tex Chemical Co.
Polysar-Butyl - Polymer Corp. Ltd.

6. Polyisobutylene (Vistenex, Oppanol)

7. Chlorobutyl

8. Polybutadiene (BR)
<u>Trade Names</u>

Ameripol CB - Goodrich-Gulf Chemical Inc.
Budene - Goodyear Tire & Rubber Co.
Cis-4 - Phillips Petroleum Co.
Cisdene - American Rubber & Chemical Co.
Diene - Firestone Synth. Rubber & Latex Co.
Duragen - General Tire & Rubber Co.
Duradene - Firestone Synth. Rubber & Latex Co.
Polysar Jaktene - Polymer Corp. Ltd.
Synpol - Tex U. S. Chemical Co.
Trans 4- Phillips Petroleum Co.

9. Ethylene Propylene (EPR, EPT)
<u>Trade Names</u>

Enjay EPR - Enjay Chemical Co.
Enjay EPT - Enjay Chemical Co.
Nordel - Elastomer Chemical E. J. DuPont
Royalene EPT - Naugatuck Chemical Div. U. S. Rubber Co.

10. Neoprene (CR, Chloroprene, Polychloropropene, (GR-M, Sovprene)

11. Nitrile (NBR, Butadiene Acrylonitrile, Buna-N, Butaprene-N, Chemigum-N, Hycar OR, GR-A, GR-N)
<u>Trade Names</u>

Chemigum - Goodyear Tire & Rubber Co.
Chemivic - Goodyear Tire & Rubber Co.
FR-N- Firestone Rubber Co.
Herecron - Heresite & Chemical Co.

Paracril - Naugatuck Chemical Div. U. S. Rubber Co.
Polysar - Polymer Corp. Ltd.
Perbunan - Naftone Inc.
Tylac - International Latex Corp.

12. Polysulfide (Alkylene Polysulfide, Thiokol)

13. Polyurethane (Polyurethane Di-Isocyanate)
<u>Trade Names</u>

Adiprene - E. S. Dupont de Nemours & Co. Inc.
Conathane - Conap Inc.
Cyanaprene - American Cyanamiel Co.
Elastothane - Thiokol Chemical Co.
Estane - B. F. Goodrich Chemical Co.
Genthane - General Tire & Rubber Co.
Mearthane - Mears Div. United Shoe Machine Corp.
Multrathane - Mobay Chemical Co.
Roylar - Naugatuck Chemical Div. U. S. Rubber Co.
Solithane - Thiokol Chemical Corp.
Texin - Mobay Chemical Co.

14. Silicone (Polysiloxane, Dimethyl Siloxane)
<u>Trade Names</u>

G. E. Silicone Rubber - Silicone Prod. Dept G. E. Co.
Silastic - Dow Corning Corp.
Union Carbide Silicone - Silicone Div., Union Carbide Corp.

15. Chlorosulfonated Polethylene (Hypalon)

16. Polyacrylic (Acryloid, Hycar Pa, Methyl Acrylate)

17. Fluoroelastomers
<u>Trade Names</u>

Fluorel - Minnesota Mining & Mfg. Co.
Kel-F - Minnesota Mining & Mfg. Co.
Silastic - Dow Corning Corp.
Viton - E. J. DuPont de Nemours & Co. Inc.

18. Methyl Rubber

19. Themoprene

20. Chlorinated Rubber (Parlon, Fornesit)

<u>Advantages of a Test Unit Hierarchy</u>

Although the user of a computerized enviromental prediction system does not appear to depend basically on a test unit categorization, such a hierarchy is indeed essential for the efficient operation of the system.

The most important aspect of the categorization is to minimize memory search time. Rather than having to search from a list which includes all levels of test units, the investigation is channeled efficiently onto the specific category of interest. For example, with 20 categories and subcategories the search time would be cut down to approximately 1/20th of the time with no categories. Thus, utilizing the test unit list in Section A of this Chapter, a query involving gasoline would be channeled to the materials section, then to the petroleum products subsection and finally to fuels where the search would begin. Hence, much unnecessary search time is avoided as only fuels are involved in the search.

Another important aspect of the hierarchy is the elimination of duplicate information yield on test units at different assembly levels. For example, an oscillator and an amplifier may contain the same resistor. Without categorization, effects on the resistor would be described under both; with categorization, only effects on the oscillator and amplifier as a whole would be described in these areas respectively, as resistors are covered in their own area. This aspect is especially important when the various possibilities of materials for construction of a test unit are considered. To account for the different materials, a cross-reference to them is used. The user can then query on the material of which his test unit is constructed to obtain the effect on it. Considering the voluminous amount of data and information which the computer must process and store, the avoidance of duplication is indeed essential to the feasibility of the system.

Beside reducing duplication, the organization of information by assembly level, so that information at one level pertains only to that level, allows for queries at discriminating levels of interest. A systems evaluator might want predictions at only the systems or assembly level, without undue concern about constituent components, parts and materials. Hence, the hierarchy saves him from having to survey a hoard of unwanted results.

Moreover, test unit identification of any specific equipment permits the prediction system to respond directly to the information demands of that equipments user.

Test Unit Properties Role in Effects Prediction

Prediction of effects on test units as a whole covers only a percentage of the total prediction problem. To fully and accurately determine the effects on test units, one must eventually study effects on specific actual properties of the test unit; thermal, mechanical, electrical, physical, and chemical.

Generalized predictions on a test unit as a whole (an amplifier will fail to operate correctly under the combined effects of high temperature and radiation) may be made by the system. However, such a prediction does not provide a basic understanding of why the amplifier failed. To determine this, the effects of temperature and radiation on the specific properties of the amplifier must be studied.

A test unit's successful operation may be measured as a function of the values of its properties. For correct operation, the critical properties must remain within certain upper and lower bounds. As long as the test unit's properties remain within their respective tolerance limits, the test unit is defined as performing satisfactorily. Once the test unit's properties stray beyond these limits, the test unit is considered to be malfunctioning. In actuality, the relationship is not necessarily so simple. Cases probably exist where a test unit works satisfactorily with a property within the tolerance limit, and then malfunctions with that property kept constant but another property varied, although this latter property is still within its own specified tolerance limits. This phenomena is due to non-linearities in the combination of properties to define the operation of a test unit.

For a first approximation, the non-linearities in the combination of properties, to define the test unit's operation as satisfactory or not, will be neglected. That is, a test unit will be taken as malfunctioning if any of its properties strays outside its tolerance limits, regardless of the values of the other properties.

For example, assume that a test unit has n properties; P_1, P_2, ----, P_n. Each property has a specific lower and upper tolerance limit, a_i and b_i respectively (i=1,2,3,----,n). Thus, the conditions for satisfactory operation of the test unit are given by:

$$a_i < P_i < b_i \tag{59}$$

for <u>all</u> i where i = 1,2,3,----,n.

The conditions for failure of the test unit are given by:

$$a_i \geq P_i \geq b_i \tag{60}$$

for <u>any</u> i where i can equal 1,2,3,----,n.

As an illustration, consider a piece of Buna S rubber as the test unit. Its properties are given as:

P_1 = Tensile strength

P_2 = Percent elongation

P_3 = Durometer hardness (A)

P_4 = Specific Gravity.

The ranges on these properties for satisfactory performance of the rubber are as follows:

$$2500 < P_1 < 4500$$

$$500 < P_2 < 900$$

$$25 < P_3 < 75$$

$$.75 < P_4 < 1.25.$$

Should any of these properties deviate outside of their respective limits, performance would be deemed unsatisfactory.

Examples of Test Unit Properties

Typical examples of test unit properties with their corresponding units of measurement for various levels of test units are given below:

Material - Rubber

Specific gravity - dimensionless ratio
Thermal conductivity - BTU/HR/Ft^2/^{o}F/Ft.
Coefficient of thermal expansion - $10^{-5}/^o$F
Dielectric Strength - Volts/mil of thickness
Electrical conductivity - mho/mil
Tensile strength - PSI
% Elongation - %
Hardness - Shore A

Part - Transistor

Forward (base to collector) current gain
β - dimensionless ratio
Input resistance - ohms
Output resistance - ohms

Component - Electrical Filter Circuit

Band width - kilocycles
Slope of gain out of passband - db/octave
Slope of phase - radians/octave

Assembly - Radio Receiver

Signal-to-noise ratio - dimensionless

Coating and Protective Devices

An environmental prediction system must take into account any coating or other protective device applied to the test unit. The coating of a test unit can determine, to a great extent, the behavior of the test unit in an environmental situation.

An ideal treatment would be to give separate predictions for the effects on a test unit depending on its coating. This, however, would produce an amount of data so voluminous as to make the system unfeasible.

For purposes of analysis, therefore, coatings may be considered as separate superimposed test units. Under the coatings nomenclature,the system stores data on the test unit coating combination, as well as on environmental effects on the coating. General protection characteristics of the coatings, on groups of test units, could also be stored in the system.

CHAPTER VI

DESCRIPTION OF SYSTEM OPERATION

System Objective and Fundamental Routines

The objective of the computerized environmental prediction system is to predict quantitative and qualitative effects of combined and sequential environmental stresses on test units from the material to the systems level. The prediction system should be capable of organizing data on properties of test units as a function of single, combined and sequential environmental factors, including data ranges of environmental factors in given regions for the different times of the year. The system should then process this data to yield analytical, graphical, tabular and verbal expressions which may be used to make predictions on the performance of test units subjected to various environmental situations.

Predicting the effects of combined and sequential environmental stresses is a basic problem to engineers who, until now, have based most predictions on single environmental factor test data. The error in the aforementioned procedure is that the nonlinear or synergistic effects of combined and sequential environmental factors are completely overlooked. As pointed out previously in Chapter IV, these effects may significantly change a test unit's performance, and must be taken into account.

The first step in attacking the combined and sequential environmental prediction problem is to obtain data, (which for the most part is unavailable at present). The system therefore presents an organized testing and data collection scheme to obtain these data. Next, a mathematical model is presented for processing these data into a form compatible for analysis by the computer. An organized test unit/environmental factor matrix is used to store the processed data (in the form of equations, graphs, tables and qualitative statements) so they may be recalled with a minimum of delay for use in predicting the effects of single, combined and sequential environmental factors on test units.

The computerized environmental prediction system can be decomposed into two fundamental routines. The first routine is concerned with the analysis of incoming test data to arrive at equations, graphs, tables and qualitative statements for use in prediction. The system then stores this information in a format which minimizes its recall time. The second routine is concerned with the recall of this information, and its use in predicting the results of an environmental-effects query to the system.

In addition to environmental-effects predictions, the system should perform auxiliary tasks such as decomposition of climatic regions and mission profiles into environmental factors, analysis of test unit composition, and identification of a test unit's properties of interest.

The basic structure of the system can be seen in the overall system block diagram shown in Figure 6-1.

To gain further insight into the operation of the system, the following sections of this chapter present a detailed explanation of each of the basic blocks shown in Figure 6-1.

It should be stressed that for the computerized environmental prediction system results to remain current and valid, an updated influx of data on environmental effects on test units is an essential need. One may view the overall prediction system as a process in which raw data on test unit-environmental relationships is fed into the system from various sources (including potential users). The computer processes this data to obtain analytical relationships, which it stores for use in response to queries from users. This concept is shown in Figure 6-2.

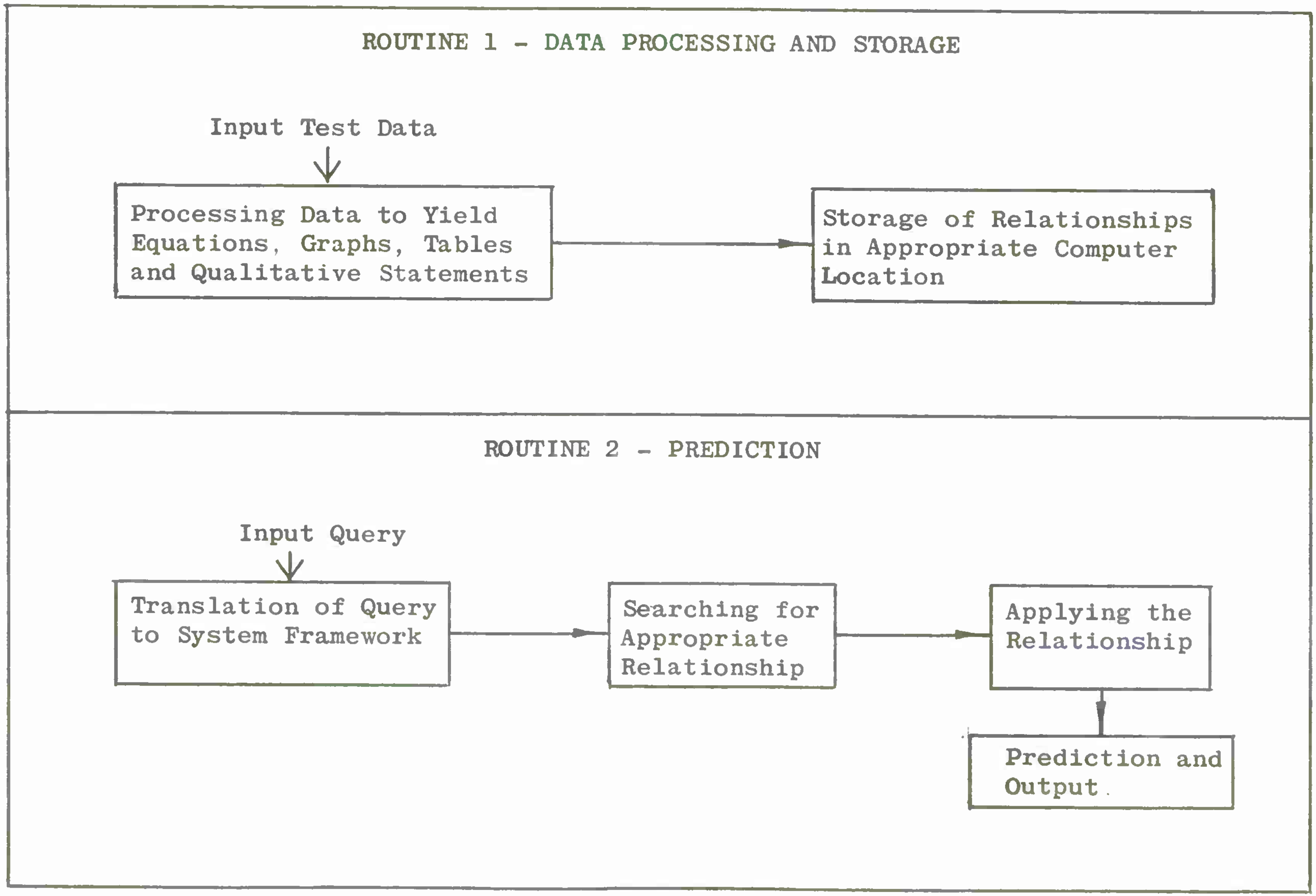

Figure 6-1. Overall System Block Diagram

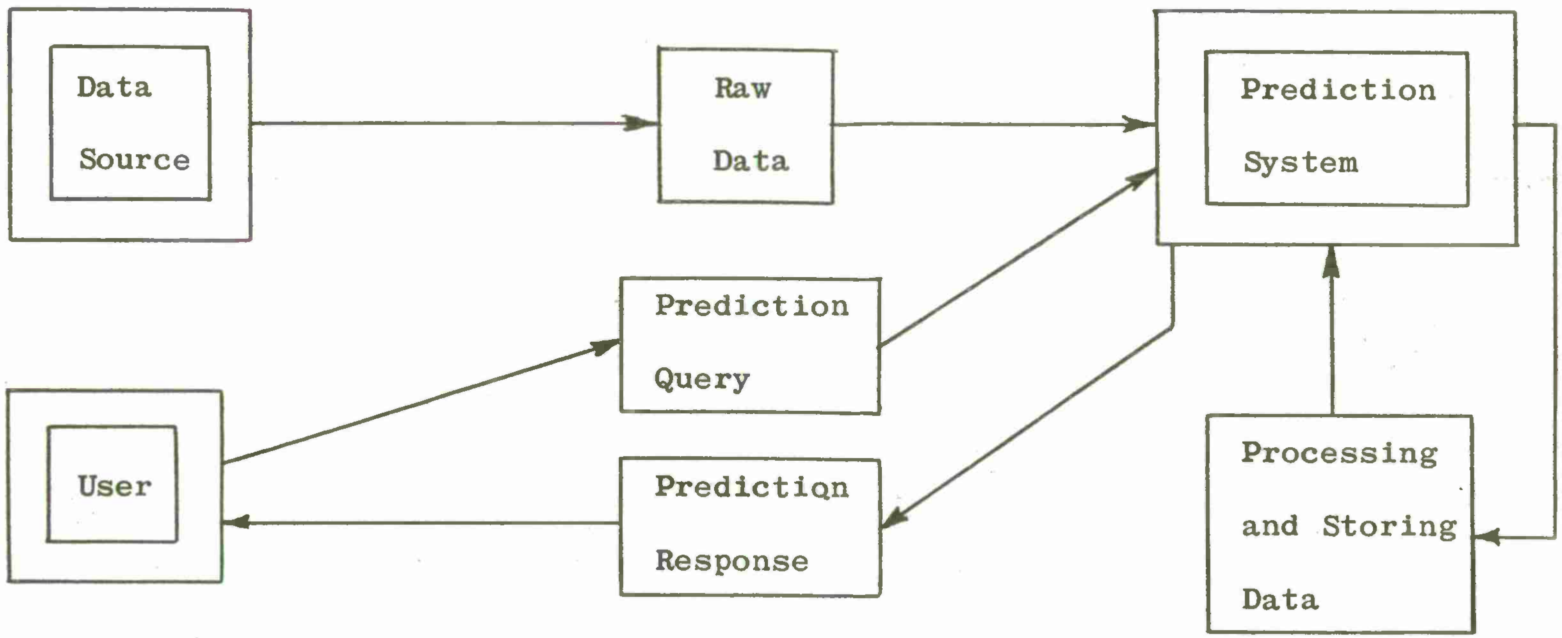

Figure 6-2. Processing and Prediction System

Prediction of Environmental Effects

In nature, a test unit is exposed to environmental factors acting in a direct combination or in sequence, seldom singly. For this reason, the prediction of environmental effects inherently involves the problem of combined environmental factors acting on the test units, producing results which differ from the effects of environmental factors occurring one at a time. The additional effect of the environments acting simultaneously or in sequence, termed the synergistic effect, can cause a test unit to fail where it otherwise would have survived in either of the single environmental factors; or it can cause a test unit to survive where it otherwise would have failed in either of the single environmental factors. There are cases where the effect of the combined or sequential environment is the pure addition of the two single environmental factor effects. In this case, no synergism is said to occur.

Most work in the environmental field has produced results on single environment tests. The effort accomplished on combined and sequential environments has been relatively meager; the data observed for combined and sequential environments, has not been unified into an analytical model that can be used to predict the effects of actual environmental situations.

There are two possible approaches to developing a model for combined and sequential environmental effects. The first approach synthesizes previous results on single environmental factors together with engineering judgment, to deduce the effects of the environments acting together or in sequence. The second approach conducts combined or sequential, and single environmental tests; the data yield is analyzed to develop analytical expressions for the combined or sequential environmental effects. in the form of equations

Although both approaches lead only to approximate descriptions of actual situations, the latter technique appears to be more valid as it utilizes results of combined and sequential environmental tests to develop a model, rather than basing the model only on results of single environment tests. The second approach is utilized in the ensuing discussion.

To obtain data on combined environments, a series of multi-level experiments is proposed. Assume an environmental situation consisting of two environmental factors acting in combination to produce an effect on a test unit, which differs from the effect of either of the environments taken singly. (Note that only two environments are considered at a time. It appears that this will suffice for the majority of actual cases). The expression (see equation (29) and related discussion) for the effect of the environmental factors acting on a test unit's property may be stated analytically as:

$$G(a,b) = F_1(a) + F_2(b) + F_3(a,b) \tag{61}$$

where:

a is environmental factor a

b is environmental factor b

$G(a,b)$ is the functional relationship of the effect on a test unit due to environmental factors a and b.

$F_1(a)$ is the functional relationship of the effect on a test unit due to environmental factor a.

$F_2(b)$ is the functional relationship of the effect on a test unit due to environmental factor b.

$F_3(a,b)$ is the functional relationship of the added effect on a test unit due to the interaction of environments a and b.

In equation 61 it is seen that the effect on a test unit, due to two combined environmental factors, can be decomposed into the linear superposition of three terms: one a function of environment a, the second a function of environment b, and the third a function of environments a and b together.

To determine these functions, for a specific property of a specific test unit exposed to two specific environmental factors, three levels of tests must be performed on the test unit.

The first level of tests is in environment a, with environment b held constant at a nominal level. Tests are run for a range of values of environmental factor a, and corresponding values of the test unit's property of interest are measured. It should be noted that any other inherently present environmental factors, beside a and b, are also held constant at a nominal level. Note that the entire series of tests must be performed on a population of sufficient size to yield meaningful results, and to permit elimination of faulty test units or erroneous measurements.

The second level of tests places the test unit in environment "b", with environment "a" held constant at a nominal level. Tests are run for a range of values of environmental factor b, and corresponding values of the test unit's property as measured in the first series, are again noted.

The third level of tests are performed in environments a and b combined. Tests are run for combinations of values of environmental factors a and b, in the ranges used in the first and second level tests, and corresponding values of the test unit's property are again measured.

The data from the first level of tests are processed to yield the function $F_1(a)$ in Equation 61. The data from the second level of tests are processed to determine the function $F_2(b)$ in Equation 61. The function $G(a,b)$ of Equation 61 is obtained by processing the data of the third level of tests. The remaining expression of Equation 61, $F_3(a,b)$ is calculated from Equation 61 by rearranging terms:

$$F_3(a,b) = G(a,b) - F_1(a) - F_2(b) \quad . \tag{62}$$

This expression measures the additional synergistic effect (beneficial or deleterious) on the test unit's property due to environments a and b acting in combination.

A new quantity is now defined, R, whioh measures the ratio of synergistic effect to total combined effect:

$$R = \frac{F_3\ (a,b)}{G\ (a,b)} \quad . \tag{63}$$

The above procedure is repeated for all properties of the test unit that are of interest, and for all test units of interest.

In the case of sequential environments (environment a followed by environment b, with different possibilities for overlap or non-overlap), the first and second level of tests of the procedure remain the same. The third level of tests is altered to tests in environment a and b applied sequentially, the amount of overlap or non-overlap depending on specified conditions. Various series of independent tests, for different amounts of overlap and non-overlap, may be conducted to obtain a complete sequential spectrum of results. The synergistic effect, $F_3(a,b)$, is again computed from Equation 62 for each different level of overlap or non-overlap.

The procedure to process the data obtained from the aforementioned tests, to determine the functions $G(a,b)$, $F_1(a)$ and $F_2(b)$, is normally too lengthy and cumbersome to be done manually. Although the mathematical approach is simple (least-square analysis), the volume of data is so great as to make the task unfeasible unless it is done by an organized computer scheme.

A computerized system, capable of processing the data obtained from the aforementioned tests and utilizing the results to predict the X effect of combined and sequential environments on test units, is described as follows:

The data from the entire series of tests on a test unit is inserted into the computer in an organized format arranged by environmental factors (a,b, or a-and-b combined or sequential), property measured, and intensity of environmental factor. For each intensity value of an environmental factor on a property of a test unit, there are several tests and measurements of the property value. These values are processed by the computer to give a mean, maximum, and minimum value points. For example, suppose 5 tests were conducted to determine the tensile strength of nitrile rubber when subjected to gamma radiation of 21.6×10^6 rads. The 5 values of tensile strength measured were:

(1) 1365 psi
(2) 1222 psi
(3) 1330 psi
(4) 1416 psi
(5) 1402 psi

The computer computes the mean value as 1347 psi and notes the maximum value as 1416 psi and the minimum as 1222 psi.

When this process is done for all the selected values within the range of the environmental factor, there is obtained a series of three points for a property for various values of the environmental factor within a range (maximum, minimum, mean). The computer then performs an independent least-square analysis for the maximum points, for the minimum points, and for the mean points, resulting in three polynomial functions to approximate the maximum, minimum, and mean values of the property versus the environmental factor. The computer is programmed so that, in performing the least-square analysis, the computations are carried out for the first through tenth power polynomials and the best fitting of these functions is selected. The selected functions for the maximum, minimum, and mean values of the property versus environmental factor a, versus environmental factor b, and versus environmental factors a-and-b combined or sequential, are now stored in the computer. The computer now applies Equation 62 to these functions to derive the synergistic function, $F_3(a,b)$. $F_3(a,b)$ is also stored in the computer. The computer now contains in storage the necessary relations to predict the total effects of environments a and b, taken singly, combined, or sequentially, on the properties of a test unit. Also the computer can isolate and predict the synergistic effect of environments a-and-b (combined or sequential), $F_3(a,b)$.

To be a complete environmental prediction system, the computer must contain in storage the aforementioned environmental-effect relations for a fairly comprehensive set of test units exposed to a wide range of environmental situations (single, combined, and sequential). These sets of test units and environmental factors are discussed in their respective prior chapters.

As a further note, the model described above does not consider time as a variable. A more advanced concept, to be considered in programming this significant aspect, would consider time as another variable in the analysis. That is, length of exposure to an environmental situation would be considered. Hence, testing would be performed for various exposure times for each of the tests mentioned in the previous system.

Independent data must be obtained for the different exposure time tests, to yield separate functions of test unit properties versus environmental factor. Thus, the amount of data collection and computations for such an advanced system would be extremely voluminous. A computer is clearly essential if such a system were to be put into operation.

To illustrate the procedure of the system, consider the following hypothetical example:

Assume environmental factors X and Y have ranges from 0 to 100 for each. A series of tests are run which expose test unit, T, to environmental factor X, environmental factor Y, and environmental factors X and Y combined. Measurements are taken of a property, value P for various levels of the environmental factors singly and in combination, with the following data resulting. (See Figures 6-3, 6-4, and 6-5.)

Level of Environmental Factor X	Value of Property, P				
	Run 1	Run 2	Run 3	Run 4	Run 5
0	135	120	125	140	130
20	85	70	75	90	80
40	65	50	55	70	60
60	55	40	45	60	50
80	65	50	55	70	60
100	85	70	75	90	80

Figure 6-3. Test 1 Environmental Factor X vs Value of Property P

Level of Environmental Factor Y	Value of Property, P				
	Run 1	Run 2	Run 3	Run 4	Run 5
0	135	120	125	140	130
20	155	140	145	160	150
40	165	150	155	170	160
60	155	140	145	160	150
80	135	120	125	140	130
100	75	60	65	80	70

Figure 6-4. Test 2 Environmental Factor Y vs Value of Property P

Level of Environmental Factor		Value of Property, P				
X	Y	Run 1	Run 2	Run 3	Run 4	Run 5
0	0	135	120	125	140	130
0	20	155	140	145	160	150
0	40	165	150	155	170	160
0	60	155	140	145	160	150
0	80	135	120	125	140	130
0	100	75	60	65	80	70
20	0	85	70	75	90	80
20	20	115	100	105	120	110
20	40	120	105	110	125	115
20	60	110	95	100	115	105
20	80	80	65	70	85	75
20	100	30	15	20	35	25
40	0	65	50	55	70	60
40	20	85	70	75	90	80
40	40	95	80	85	100	90
40	60	80	65	70	85	75
40	80	50	35	40	55	45
40	100	0	0	0	0	0
60	0	55	40	45	60	50
60	20	75	60	65	80	70
60	40	85	70	75	90	80
60	60	70	55	60	75	65
60	80	35	20	25	40	30
60	100	0	0	0	0	0
80	0	65	50	55	70	60
80	20	85	70	75	90	80
80	40	90	75	80	95	85
80	60	75	60	65	80	70
80	80	40	25	30	45	35
80	100	0	0	0	0	0
100	0	85	70	75	90	80
100	20	105	90	95	110	100
100	40	110	95	100	115	105
100	60	95	80	85	100	90
100	80	60	45	50	65	55
100	100	5	0	5	10	5

Figure 6-5. Test 3 Environmental Factors X and Y combined vs Value of Property P

The first step the computer performs is to obtain the mean, minimum, and maximum values of the data. These are shown in Figures 6-6, 6-7, and 6-8.

Level of Environmental Factor X	Minimum Value of Property P	Mean Value of Property P	Maximum Value of Property P
0	120	130	140
20	70	80	90
40	50	60	70
60	40	50	60
80	50	60	70
100	70	80	90

Figure 6-6, Test 1-Environmental Factor X vs Mean, Minimum, and Maximum Value of Property P

Level of Environmental Factor Y	Minimum Value of Property P	Mean Value of Property P	Maximum Value of Property P
0	120	130	140
20	140	150	160
40	150	160	170
60	140	150	160
80	120	130	140
100	60	70	80

Figure 6-7. Test 2-Environmental Factor Y vs Mean, Minimum and Maximum Values of Property P

Level of Environmental Factor		Minimum Value of Property P	Mean Value of Property P	Maximum Value of Property P
X	Y			
0	0	120	130	140
0	20	140	150	160
0	40	150	160	170
0	60	140	150	160
0	80	120	130	140
0	100	60	70	80
20	0	70	80	90
20	20	100	110	120
20	40	105	115	125
20	60	95	105	115
20	80	65	75	85
20	100	15	25	35
40	0	50	60	70
40	20	70	80	90
40	40	80	90	100
40	60	65	75	85
40	80	35	45	55
40	100	0	0	0
60	0	40	50	60
60	20	60	70	80
60	40	70	80	90
60	60	55	65	75
60	80	20	30	40
60	100	0	0	0
80	0	50	60	70
80	20	70	80	90
80	40	75	85	95
80	60	60	70	80
80	80	25	35	45
80	100	0	0	0
100	0	70	80	90
100	20	90	100	110
100	40	95	105	115
100	60	80	90	100
100	80	45	55	65
100	100	0	5	10

Figure 6-8. Test 3-Environmental Factors X and Y Combined vs Mean, Minimum, and Maximum Values of Property P

Next the computer performs a least-square analysis to determine the functions describing the variations of property P with environmental factor X, environmental factor Y, and environmental factors X and Y combined respectively. In actuality, the computer would compute these functions using first through tenth power polynomial approximations and then select the best fitting function. However, as this procedure is too cumbersome for manual computation, a second power polynomial will be assumed to give the best fit and will be used throughout the example. In addition, for simplicity in presentation, only the average values of the data will be used in this discussion, whereas the computer would calculate the functions for the maximum and minimum data points also.

Test 1. Least Square Analysis - Environmental Factor X

The function to be fitted to the data is given by

$$P = aX^2 + bX + c \tag{64}$$

	X	P	X^2	X^3	X^4	X^2P	XP
	0	130	0	0	0	0	0
	20	80	400	8,000	160,000	32,000	1,600
	40	60	1,600	64,000	2,560,000	96,000	2,400
	60	50	3,600	216,000	12,960,000	180,000	3,000
	80	60	6,400	512,000	40,960,000	384,000	4,800
	100	80	10,000	1,000,000	100,000,000	800,000	8,000
Total	300	460	22,000	1,800,000	156,640,000	1,492,000	19,800
n = 6							

The expanded data, above, is used in the following three equations which are solved for a, b and c of Equation 64, which is the function of property P vs environmental factor X.

$$\sum_{i=1}^{n} X_i^4 a + \sum_{i=1}^{n} X_i^3 b + \sum_{i=1}^{n} X_i^2 c = \sum_{i=1}^{n} X_i^2 P_i \tag{65}$$

$$\sum_{i=1}^{n} X_i^3 a + \sum_{i=1}^{n} X_i^2 b + \sum_{i=1}^{n} X_i c = \sum_{i=1}^{n} X_i P_i \tag{66}$$

$$\sum_{i=1}^{n} X_i^2 a + \sum_{i=1}^{n} X_i b + \sum_{i=1}^{n} X_i^o c = \sum_{i=1}^{n} P_i \quad (67)$$

Substituting the data in Equations 65, 66, 67 yields

$$156{,}640{,}000a + 1{,}800{,}000b + 22{,}000c = 1{,}492{,}000 \quad (68)$$

$$1{,}800{,}000a + 22{,}000b + 300c = 19{,}800 \quad (69)$$

$$22{,}000a + 300b + 6c = 460. \quad (70)$$

Solving for a, b, and c yields:

$a = .0212$

$b = -2.58$

$c = 127.78$.

Hence, the equation for property P vs. environmental factor X is given by:

$$P = .0212X^2 - 2.58X + 127.8 \quad . \quad (71)$$

Test 2. Least Squares Analysis-Environmental Factor Y

The function to be fitted to the data is given by:

$$P = aY^2 + bY + c, \quad (72)$$

	Y	P	Y^2	Y^3	Y^4	Y^2P	YP
	0	130	0	0	0	0	0
	20	150	400	8,000	160,000	60,000	3,000
	40	160	1,600	64,000	2,560,000	256,000	6,400
	60	150	3,600	216,000	12,960,000	540,000	9,000
	80	130	6,400	512,000	40,960,000	832,000	10,400
	100	70	10,000	1,000,000	100,000,000	700,000	7,000
Total	300	790	22,000	1,800,000	156,640,000	2,388,000	35,800
				n = 6			

The following three equations in a, b, and c result:

$$156{,}640{,}000a + 1{,}800{,}000b + 22{,}000c = 388{,}000 \quad (73)$$

$$1{,}800{,}000a + 22{,}000b + 300c = 35{,}800 \quad (74)$$

$$22{,}000a + 300b + 6c = 790 \quad . \quad (75)$$

Solving for a, b and c yield:

$a = -.0231$

$b = 1.78$

$c = 127.3$.

Hence, the equation for property P vs environmental factor Y is given by:

$$P = -.0231Y^2 + 1.78Y + 127.3 \quad . \tag{76}$$

Test 3. Least Squares Analysis - Environmental Factor X and Y combined

The function to be fitted to the data is given by:

$$P = aX^2 + bX + cY^2 + dY + eXY + f \tag{77}$$

(See Figure 6-9)

X	Y	P	X^2	X^3	X^4	Y^2
0	0	130	0	0	0	0
0	20	150	0	0	0	400
0	40	160	0	0	0	1,600
0	60	150	0	0	0	3,600
0	80	130	0	0	0	6.400
0	100	70	0	0	0	10,000
20	0	80	400	8,000	160,000	0
20	20	110	400	8,000	160,000	400
20	40	115	400	8,000	160,000	1,600
20	60	105	400	8,000	160,000	3,600
20	80	75	400	8,000	160,000	6,400
20	100	25	400	8,000	160,000	10,000
40	0	60	1,600	64,000	2,560,000	0
40	20	80	1,600	64,000	2,560,000	400
40	40	90	1,600	64,000	2,560,000	1,600
40	60	75	1,600	64,000	2,560,000	3,600
40	80	45	1,600	64,000	2,560,000	6,400
40	100	0	1,600	64,000	2,560,000	10,000
60	0	50	3,600	216,000	12,960,000	0
60	20	70	3,600	216,000	12,960,000	400
60	40	80	3,600	216.000	12,960,000	1,600
60	60	65	3,600	216,000	12,960,000	3,600
60	80	30	3,600	216,000	12,960,000	6,400
60	100	0	3,600	216,000	12,960,000	10,000
80	0	60	6,400	512,000	40,960,000	0
80	20	80	6,400	512,000	40,960,000	400
80	40	85	6,400	512,000	40,960,000	1,600
80	60	70	6,400	512,000	40,960,000	3,600
80	80	35	6,400	512,000	40,960,000	6,400
80	100	0	6,400	512,000	40,960,000	10,000
100	0	80	10,000	1,000,000	100,000,000	0
100	20	100	10,000	1,000,000	100,000.000	400
100	40	105	10,000	1,000,000	100,000,000	1,600
100	60	90	10,000	1,000,000	100,000,000	3,600
100	80	55	10,000	1,000,000	100,000,000	6,400
100	100	5	10.000	1,000,000	100,000,000	10,000
Tot. 1,800	1,800	2,710	132,000	10,800,000	939,840,000	132,000
n = 36						

Figure 6-9a. Least Squares Analysis - Environmental Factors X and Y Combined.

	Y^3	Y^4	X^2Y^2	X^2Y	X^3Y	XY	XY^2
	0	0	0	0	0	0	0
	8,000	160,000	0	0	0	0	0
	64,000	2,560,000	0	0	0	0	0
	216,000	12,960,000	0	0	0	0	0
	512,000	40,960,000	0	0	0	0	0
	1,000,000	100,000,000	0	0	0	0	0
	0	0	0	0	0	0	0
	8,000	160,000	160,000	8,000	160,000	400	8,000
	64,000	2,560,000	640,000	16,000	320,000	800	32,000
	216,000	12,960,000	1,440,000	24,000	480,000	1,200	72,000
	512,000	40,960,000	2,560,000	32,000	640,000	1,600	128,000
	1,000,000	100,000,000	4,000,000	40,000	800,000	2,000	200,000
	0	0	0	0	0	0	0
	8,000	160,000	640,000	32,000	1,280,000	800	16,000
	64,000	2,560,000	2,560,000	64,000	2,560,000	1,600	64,000
	216,000	12,960,000	5,760,000	96,000	3,840,000	2,400	144,000
	512,000	40,960,000	10,240,000	128,000	5,120,000	3,200	256,000
	1,000,000	100,000,000	16,000,000	160,000	6,400,000	4,000	400,000
	0	0	0	0	0	0	0
	8,000	160,000	1,440,000	72,000	4,320,000	1,200	24,000
	64,000	2,560,000	5,760,000	144,000	8,640,000	2,400	96,000
	216,000	12,960,000	12,960,000	216,000	12,960,000	3,600	216,000
	512,000	40,960,000	23,040,000	288,000	17,280,000	4,800	384,000
	1,000,000	100,000,000	36,000,000	360,000	21,600,000	6,000	600,000
	0	0	0	0	0	0	0
	8,000	160,000	2,560,000	128,000	10,240,000	1,600	32,000
	64,000	2,560,000	10,240,000	256,000	20,480,000	3,200	128,000
	216,000	12,960,000	23,040,000	384,000	30,720,000	4,800	288,000
	512,000	40,960,000	40,960,000	512,000	40,960,000	6,400	512,000
	1,000,000	100,000,000	64,000,000	640,000	51,200,000	8,000	800,000
	0	0	0	0	0	0	0
	8,000	160,000	4,000,000	200,000	20,000,000	2,000	40,000
	64,000	2,560,000	16,000,000	400,000	40,000,000	4,000	160,000
	216,000	12,960,000	36,000,000	600,000	60,000,000	6,000	360,000
	512,000	40,960,000	64,000,000	800,000	80,000,000	8,000	640,000
	1,000,000	100,000,000	100,000,000	1,000,000	100,000,000	10,000	1,000,000
Tot.	10,800,000	939,840,000	484,000,000	6,600,000	540,000,000	90,000	6,600,000
			n = 36				

Figure 6-9b. Least Squares Analysis - Environmental Factors X and Y Combined

XY^3	X^2P	XP	Y^2P	YP	XYP
0	0	0	0	0	0
0	0	0	60,000	3,000	0
0	0	0	256,000	6,400	0
0	0	0	540,000	9,000	0
0	0	0	832,000	10,400	0
0	0	0	700,000	7,000	0
0	32,000	1,600	0	0	0
160,000	44,000	2,200	44,000	2,200	44,000
1,280,000	46,000	2,300	184,000	4,600	92,000
4,320,000	42,000	2,100	378,000	6,300	126,000
10,240,000	30,000	1,500	480,000	6,000	120,000
20,000,000	10,000	500	250,000	2,500	50,000
0	96,000	2,400	0	0	0
320,000	128,000	3,200	32,000	1,600	64,000
2,560,000	144,000	3,600	144,000	3,600	144,000
8,640,000	120,000	3,000	270,000	4,500	180,000
20,480,000	72,000	1,800	288,000	3,600	144,000
40,000,000	0	0	0	0	0
0	180,000	3,000	0	0	0
480,000	252,000	4,200	28,000	1,400	84,000
3,840,000	288,000	4,800	128,000	3,200	192,000
12,960,000	234,000	3,900	234,000	3,900	234,000
30,720,000	108,000	1,800	192,000	2,400	144,000
60,000,000	0	0	0	0	0
0	384,000	4,800	0	0	0
640,000	512,000	6,400	32,000	1,600	128,000
5,120,000	544,000	6,800	136,000	3,400	272,000
17,280,000	448,000	5,600	252,000	4,200	336,000
40,960,000	224,000	2,800	224,000	2,800	224,000
80,000,000	0	0	0	0	0
0	800,000	8,000	0	0	0
800,000	1,000,000	10,000	40,000	1,600	160,000
6,400,000	1,050,000	10,500	168,000	4,200	420,000
21,600,000	900,000	9,000	324,000	5,400	540,000
51,200,000	550,000	5,500	352,000	4,400	440,000
100,000,000	50,000	500	50,000	500	50,000
Tot. 540,000,000	8,288,000	111,800	6,618,000	109,700	4,188,000
n = 36					

Figure 6-9c. Least Squares Analysis - Environmental Factors X and Y Combined

The expanded data, above, is used in the following six equations which are solved for a, b, c, d, e, and f of Equation 77 to yield the function of property P vs. environmental factors X and Y combined.

$$\sum_{i-1}^{n} X_i^4 a + \sum_{i=1}^{n} X_i^3 b + \sum_{i=1}^{n} X_i^2 Y_i^2 c + \sum_{i=1}^{n} X_i^2 Y_i d + \sum_{i=1}^{n} X_i^3 Y_i e +$$

$$\sum_{i=1}^{n} X_i^2 f = \sum_{i=1}^{n} X_i^2 P_i \tag{78}$$

$$\sum_{i=1}^{n} X_i^3 a + \sum_{i=1}^{n} X_i^2 b + \sum_{i=1}^{n} X_i Y_i^2 c + \sum_{i=1}^{n} X_i Y_i d + \sum_{i=1}^{n} X_i^2 Y_i e +$$

$$\sum_{i=1}^{n} X_i f = \sum_{i=1}^{n} X_i P_i \tag{79}$$

$$\sum_{i=1}^{n} X_i^2 Y_i^2 a + \sum_{i=1}^{n} X_i Y_i^2 b + \sum_{i=1}^{n} Y_i^4 c + \sum_{i=1}^{n} Y_i^3 d + \sum_{i=1}^{n} X_i Y_i^3 e +$$

$$\sum_{i=1}^{n} Y_i^2 f = \sum_{i=1}^{n} Y_i^2 P_i \tag{80}$$

$$\sum_{i=1}^{n} X_i^2 Y_i a + \sum_{i=1}^{n} X_i Y_i b + \sum_{i=1}^{n} Y_i^3 c + \sum_{i=1}^{n} Y_i^2 d + \sum_{i=1}^{n} X_i Y_i^2 e +$$

$$\sum_{i=1}^{n} Y_i f = \sum_{i=1}^{n} Y_i P_i \tag{81}$$

$$\sum_{i=1}^{n} X_i^3 Y_i a + \sum_{i=1}^{n} X_i^2 Y_i b + \sum_{i=1}^{n} X_i Y_i^3 c + \sum_{i=1}^{n} X_i Y_i^2 d + \sum_{i=1}^{n} X_i^2 Y_i^2 e +$$

$$\sum_{i=1}^{n} X_i Y_i f = \sum_{i=1}^{n} X_i Y_i P_i \tag{82}$$

$$\sum_{i=1}^{n} X_i^2 a + \sum_{i=1}^{n} X_i b + \sum_{i=1}^{n} Y_i^2 c + \sum_{i=1}^{n} Y_i d + \sum_{i=1}^{n} X_i Y_i e + nf = \sum_{i=1}^{n} P_i \tag{83}$$

$n = 36$ in above equations

Substituting the data in Equations 78, 79, 80, 81, 82, and 83 yields

$$939{,}840{,}000a + 10{,}800{,}000b + 484{,}000{,}000c + 6{,}600{,}000d + 540{,}000{,}000e + 132{,}000f = 8{,}288{,}000 \tag{84}$$

$$10{,}800{,}000a + 132{,}000b + 6{,}600{,}000c + 90{,}000d + 6{,}600{,}000e + 1{,}800f = 111{,}800 \tag{85}$$

$$484{,}000{,}000a + 6{,}600{,}000b + 939{,}840{,}000c + 10{,}800{,}000d + 540{,}000{,}000e + 132{,}000f = 6{,}618{,}000 \tag{86}$$

$$6{,}600{,}000a + 90{,}000b + 10{,}800{,}000c + 132{,}000d + 6{,}600{,}000e + 1{,}800f = 109{,}700 \tag{87}$$

$$540{,}000{,}000a + 6{,}600{,}000b + 540{,}000{,}000c + 6{,}600{,}000d + 484{,}000{,}000e + 90{,}000f = 4{,}188{,}000 \tag{88}$$

$$132{,}000a + 1{,}800b + 132{,}000c + 1{,}800d + 90{,}000e + 36f = 2{,}710 \tag{89}$$

Solving the system of equations for a, b, c, d, e and f yields

$a = .0212$
$b = -2.58$

$c = -.0231$

$d = 1.78$

$e = .0025$

$f = 127.5$.

Hence the equation for property P vs environmental factors X and Y combined is given by:

$$P = .0212X^2 - 2.58X - .0231Y^2 + 1.78Y - .0025XY + 127.5. \quad (90)$$

The computer now uses Equations 70, 75 and 89 in Equation 62 with:

$$F_1(X) = .0212X^2 - 2.58X + 127$$
$$F_2(Y) = -.0231Y^2 + 1.78Y + 127$$

and

$$G(X,Y) = .0212X^2 - 2.58X - .0231Y^2 + 1.78Y - .0025XY + 127$$

to solve for the synergistic effect, $F_3(X, Y)$, which is given by

$$F_3(X,Y) = G(X,Y) - F_1(X) - F_2(Y) = -.0025XY - 127. \quad (91)$$

Next the computer calculates the ratio of synergistic to total combined effect by using Equations 90, and 91 in Equation 63 to yield:

$$R = \frac{F_3(X,Y)}{G(X,Y)} = \frac{-.0025XY - 127}{.0212X^2 - 2.58X - .0231Y^2 + 1.78Y - .0025XY + 127} \quad (92).$$

49-a

The computer now stores equation 71 in its memory in the location under test unit T, property P, and environmental factor X. 49-b Equation 76 is stored in the location under test 49-c unit T, property P and environmental factor Y. Equations 90, 60 91 and 61 92 are stored in the location under test unit T, property P and environmental factors X and Y combined. The system is now ready to make predictions on property P of test unit T when subjected to environmental factor X, environmental factor Y and environmental factors X and Y combined.

That is, for a given value of environmental factor X, environmental factor Y or both, the computer can predict the value of property P of test unit T. It can also predict the synergistic effect due to the combined environments.

Assume, for a given property of a given test unit, upper and lower bounds are established beyond which the test unit is said to malfunction. Then, upon evaluation of the property value for a given environmental situation, the computer can also predict if the environmental situation will drive the test unit's property to a point of malfunction.

When the data analyzed by the least-squares method (as explained previously in this chapter) does not lend itself to an accurate and workable analytical expression, the points could be reduced alternatively to a curve (graphical), or put into tabular form. In the case of graphs, values may be picked from the curves. With tables, linear and higher order interpolations are used to solve for values between the values contained in the table.

In some cases (especially at the onset of such a system), data for quantitative analysis of environmental effects is not yet available. In such a case, the system would store qualitative data on the areas in question. When a query enters the system about these areas, rather than leaving a complete void the system would print out the corresponding qualitative statement.

A logic block diagram of the data analysis routine covered in this chapter is presented in Figure 6-10. Note that qualitative information bypasses this routine and goes directly to the next routine, storage of information and relationships.

A similar data analysis routine obtains analytical relationships from quantitative data on environmental factors vs. months of the year for different climatic regions of the earth as described in Chapter IV. These relationships are useful in answering a query which involves a test unit specifically in a climatic region for a given month of the year, rather than a test unit in a given level of an environmental factor.

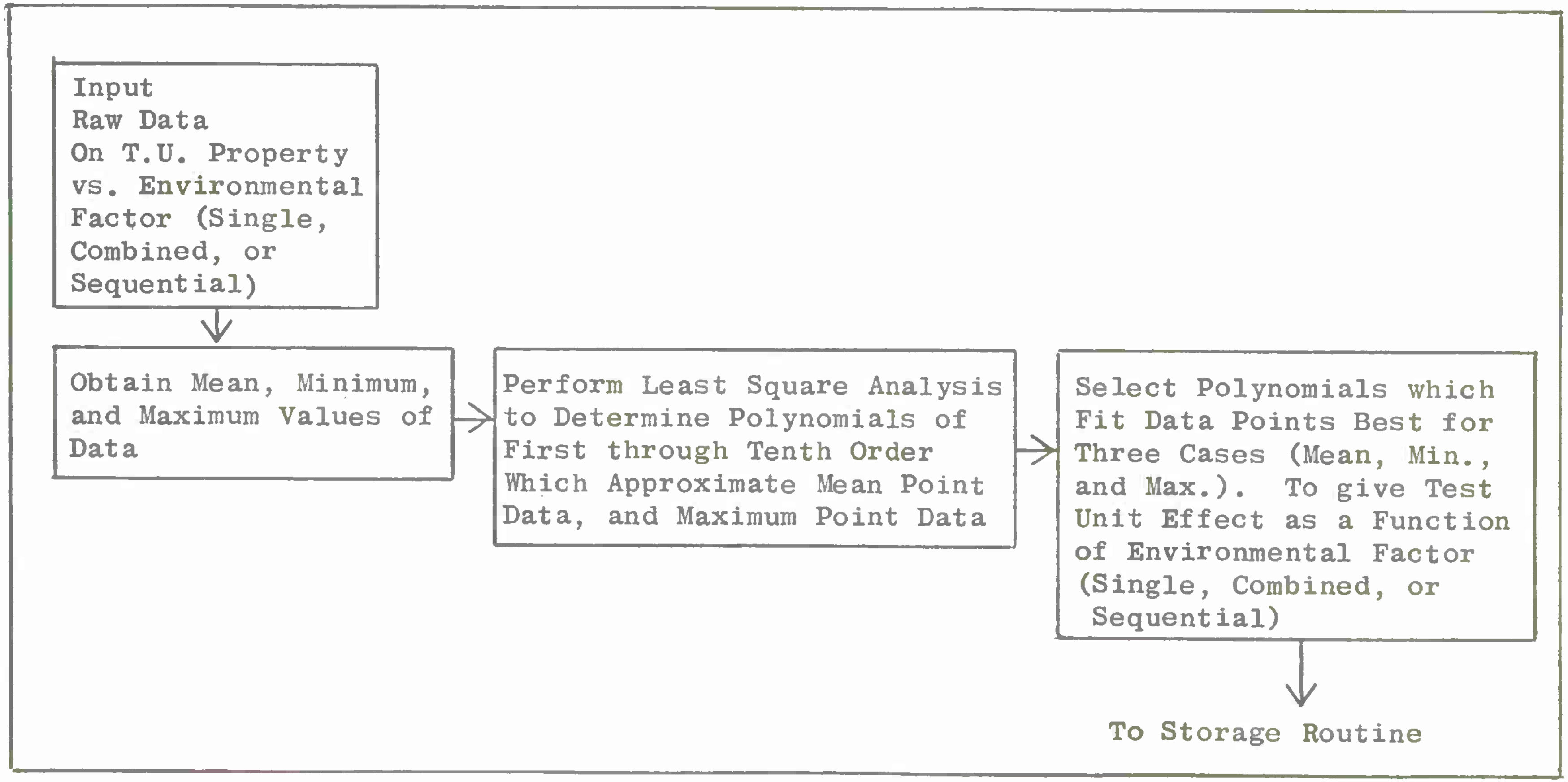

Figure 6-10, Block Diagram of Data Analysis Routine

Information Storage in a System Framework

Once the quantitative data is processed into relationships and the qualitative data is obtained, the system must store this information in a manner which permits its prompt recall when it is needed for a response to a query.

In this capacity, the formats described in Chapters IV and V, for environmental factors and test units respectively, are merged into an all-encompassing matrix of test units vs. environmental factors. The information stored in the computer is arranged by the cells of the matrix. Each test unit-environmental factor (single, combined or sequential) cell is further subdivided by test unit property and environmental subfactor. The form of a typical section of the matrix is illustrated in Figure 6-11.

Within each cell of the matrix are stored the qualitative information and quantitative relationships for the given test unit or test unit property and environmental factor or subfactor (single, combined or sequential). Note that a row of the matrix is allotted for each test unit. In these cells, information is stored on the entire test unit vs. environmental factors, rather than on the test unit properties vs. environmental factors as stored in the remaining matrix rows.

The test unit classifications of the matrix are arranged under the hierarchy described in Chapter V (materials, parts, components, assemblies, and systems).

As an example of the aforementioned matrix storage scheme, consider the materials level of the test unit hierarchy; more specifically, the material rubber. A typical segment of the matrix, under which rubber is covered, would appear as shown in Figure 6-12. This is not meant to be a complete list, but only illustrative of the environmental factor entries possible under a typical test unit categorization.

The computer operation in storage of processed quantitative data and qualitative information consists of:

- Determination of the test unit level (example - material).
- Determination of the test unit category (example - rubber).

ENVIRONMENTAL FACTORS													
Test Unit and Properties	A			B	C		D			E		F	
	A_1	A_2	A_3		C_1	C_2	D_1	D_2	D_3	E_1	E_2	F_1	F_2
1.													
a)													
b)													
c)													
d)													
2.													
a)													
b)													
3.													
a)													
b)													
c)													
4.													
a)													
5.													
a)													
b)													
c)													
d)													
e)													
6.													
a)													
b)													
c)													
d)													

Figure 6-11. Computer Storage Matrix Composition

Material Rubber	Environmental Factors									Chemical		
	Gamma Radiation	Temp.-Low Pressure Combined	Ozone-Temperature Combined	Humidity	Humidity-Temperature Sequential	Ozone Vibration Combined	Ozone Vibration Sequential	Gamma Radiation Low Pressure Combined	Immersion in N_2O_4	Immersion in 50/50 Hydrazine/UDMH	Immersion in CLO_3F
Natural											
-Tensile Strength											
-200% Modulus											
-% Elongation											
- Hardness											
-% Weight Loss											
Synthetic Polyisoprene											
-% Weight Loss											
Styrene Butadiene											
-Tensile Strength											
-% Elongation											
- Hardness											
- Elasticity											

Figure 6-12. Segment of Computer Storage Matrix

- o Determination of the test unit subcategory, if any, (example - styrene butadiene).
- o Determination of the test unit property, if any, (example - tensile strength).
- o Determination of the environmental factors (example - temperature/pressure combined).
- o Determination of the environmental subfactor, if any, (example - temperature/vacuum combined).
- o Storage of information in the assigned location.

Figure 6-13 presents a block diagram of the computer storage procedure.

In addition to the aforementioned data and information, the computer stores the analytical relationships obtained from the quantitative data on values of environmental factors in the various climatic regions for different months of the year. (See Chapter IV). This information is stored separately from the aforementioned matrix, in a section of the computer memory devoted to auxiliary information. This section can also store other helpful information such as a test unit taxonomy (including trade names), uses of test units, mission profile categories for test units (giving the probable environmental factors to be encountered), and test unit breakdowns into lower level categories. The latter service gives, for example, the parts of which a component consists (e.g., for an amplifier, the parts are transistor, resistor, capacitor).

The auxiliary information may be called on to aid in responding to an environmental-effects prediction problem, or to answer entire queries.

<u>Translation of Problem to a System Framework</u>

Due to the enormity of the environmental-effects prediction problem, feasibility of a system to handle such a project depends to a great extent on the ability to standardize sections of the problem. For this reason, a standard input format must be developed for incoming queries. This averts the necessity for different query analysis procedures for each query, which wastes considerable computer memory space.

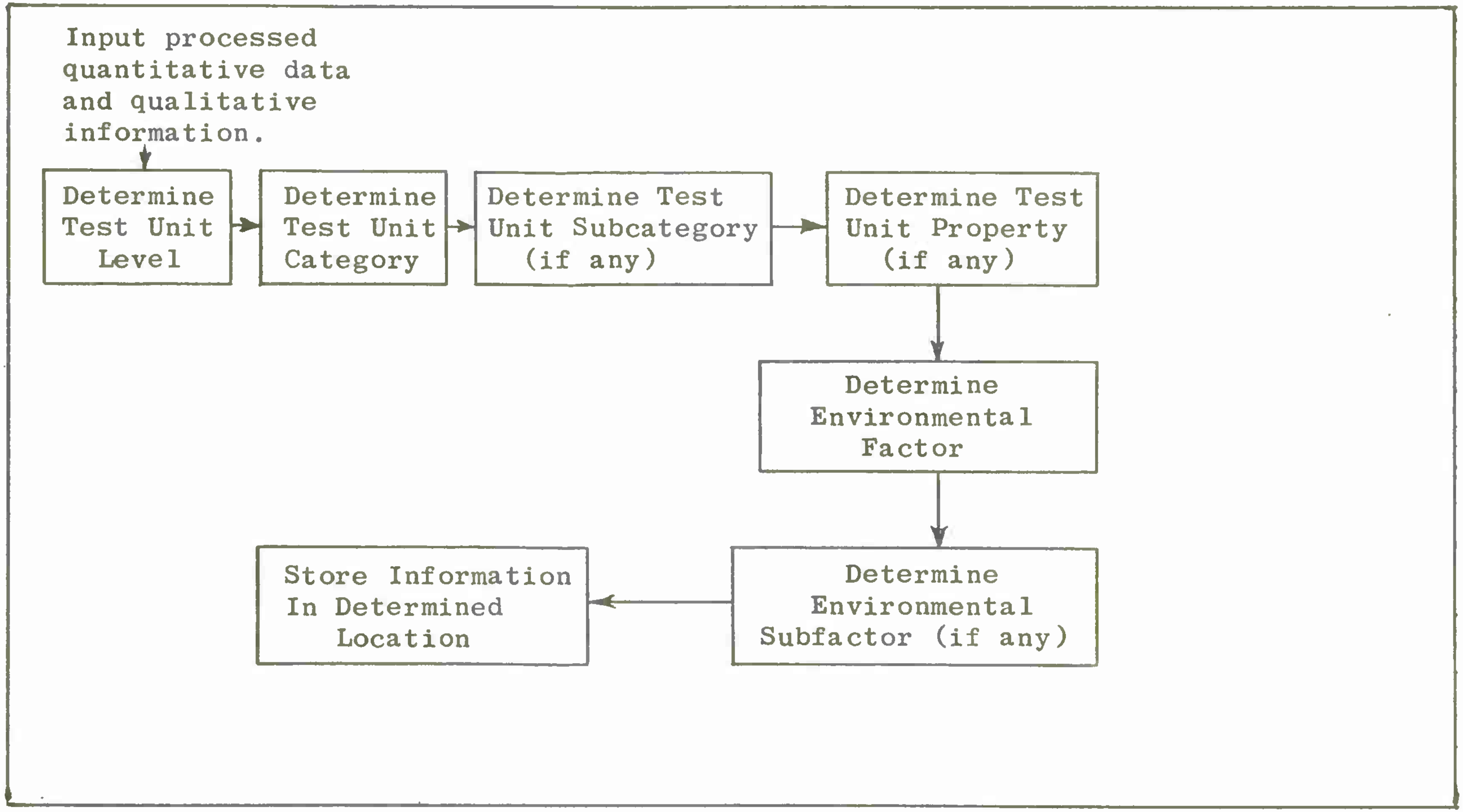

Figure 6-13. Block Diagram of Computer Storage Procedure

Queries to the computer involve test units, test unit properties, environmental factors, climatic regions, and environmental factors effects on test units. These were discussed in Chapter III. Consistent with the type of queries which the system is capable of handling, the format for queries shown in Figure 6-14 is suggested. The queries are written in the form of descriptors involving test units, test unit properties, environmental factors (including ranges and values), climatic regions, mission profiles, month of the year.

Note that a blank under a descriptor implies that the query is not concerned with that descriptor; a question mark under a descriptor or descriptor value indicates that the query asks to solve for that descriptor or descriptor value.

Since the system is capable of handling several query types (as shown in Chapter III), descriptors must be established to distinguish these types.

The query posed in Figure 6-14 is the computer format for a question on the tensile strength of Butadiene Styrene rubber in the sequential environmental situation of 10 pphm ozone followed by 5" amplitude, 500 cps vibration.

Once a query format is established for the system, it is adhered to for all queries of that type. The computer is programmed to translate only those questions presented in the selected format. Any error in format produces erroneous results.

The possibilities for words used as descriptors are limited to only those words which the computer is programmed to handle. Should any other word be used, the computer would print out a standard answer indicating an error in input. To ensure correct terminology the user would have to consult a system terminology thesaurus before posing a query to the system. This thesaurus would contain a list of all the acceptable words which can be used in the descriptor categories illustrated in the query format of Figure 6-14. It would also contain a cross-referencing of alternatively acceptable words. For example, in the query on Butadiene Styrene rubber, the user originally may have used the term GR-S rubber for his query. Upon checking with the thesaurus, he would have found that the system uses the word Butadiene Styrene rubber to mean GR-S rubber.

Query Descriptors

- Test Unit Level: material
- Test Unit: rubber
- Test Unit Subcategory: Butadiene Styrene
- Test Unit Properties: Tensile Strength
- Value of TU Property:
- Regional Location:
- Environmental Factors: ozone and vibration - sequential
- Values of Environmental Factors:

  ozone 10 pphm

  vibration 5" peak amplitude at 500 cps.
- Subenvironmental Factors:
- Values of Subenvironmental Factors:
- Month of the Year:
- Mission Profile:
- Type of Query: 3G

Figure 6-14. Possible Query Format

The possibility of an automated computer thesaurus does also exist, whereby the computer would be programmed to automatically change the user's queries to correct computer terminology and format. However, due to the enormity of the environmental prediction problem, it is probably wise to have these auxiliary features done manually at first, with a switch to automation where feasible from the standpoint of computer storage location.

Searching for Appropriate Relationship

Once the computer accepts the input query through its translation to machine language, the search for appropriate information and/or analytical relationships is begun. The computer is programmed to locate the cell in the matrix which contains the information called for in the query. This is accomplished through a search procedure which matches descriptors of the query with descriptors of the matrix cells.

As described in this Chapter, the information and analytical expressions are stored in appropriate cells of a matrix arranged by test units, test unit property, and environmental factor descriptors. The queries are expressed by this same format as explained in this Chapter. Hence, the computer matches the corresponding descriptors of query and matrix cell for each of the descriptors present in the query.

As noted in this Chapter, the descriptors are arranged in a hierarchy for ease in the search procedure. The computer, therefore, has to check only through the test unit and environmental factor descriptors in the appropriate level category.

Since the search procedure is so basic to the successful operation of the system, a block diagram of the technique used is presented in Figure 6-15. This illustrates the steps taken to approach and then pinpoint the appropriate matrix cell for an environmental-effects query.

Note that queries involving the auxiliary stored information, discussed in this Chapter, are channeled to search routines which locate this separate information. The computer identifies the need for this from the "query type" code. The auxiliary information is then added to the query input in query types which require this. For queries based solely on auxiliary information, this information is printed out when located.

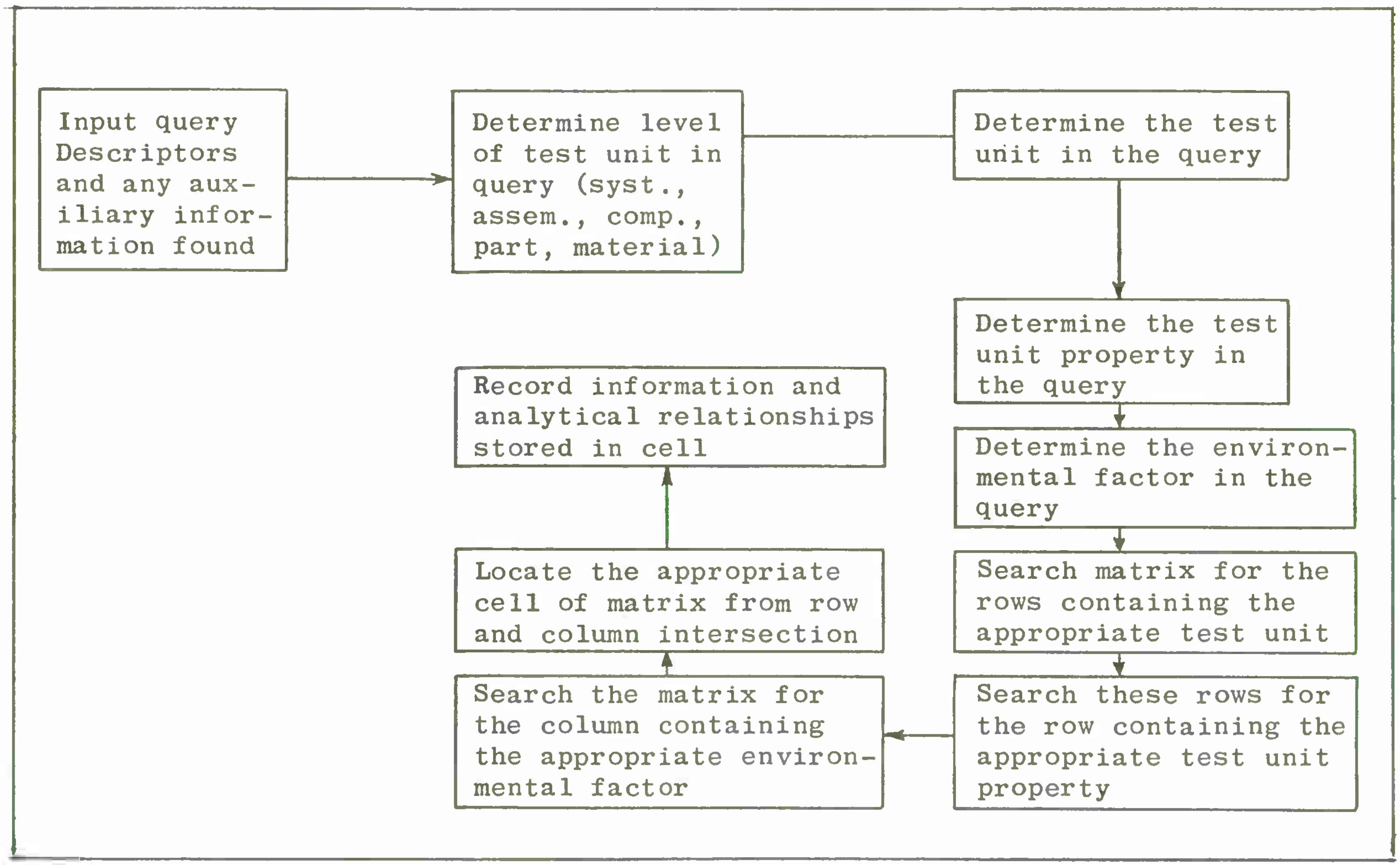

Figure 6-15. Block Diagram of Computer Search Routine for Test-Environmental Factor Matrix

Application of Relationship to Give Prediction Output

As previously mentioned, the information stored within the matrix cells will be in the form of qualitative information, equations, graphs, and tables. The qualitative information is stored only in the absense of quantitative relationships. The stored qualitative information is not operated on, but simply printed out when a query refers to the cell in which it is contained.

As for the graphical data, these will only be used when it is too unwieldy to express the pictorial relationship by an analytical expression. It is believed that this will occur only for a small percentage of the cases. In using graphical data, the computer stores the graph by some approximate discrete method, and values for test unit properties responding to an environmental situation are picked off the graph and recorded in the computer. The value of the test unit's property is then compared against the property's upper and lower limits for acceptable test unit operation.

When all the test unit properties are evaluated, for the given environmental situation, and compared against their respective upper and lower limits, the computer can make a prediction on whether or not the test unit will survive the environmental conditions, and on the margin of survival or failure.

The case of tabular data is probably the least likely of all possible stored information due to the inaccuracies of interpolating between the discrete points contained in the table. The tabular data will usually be processed, before being stored in the matrix, by a method such as least-square analysis (as described in this chapter) to yield analytical expressions for the contained relationships.

The most probable type of stored data in the matrix will be analytical expression (equations) relating test unit property value to level of environmental factor(s). These equations were determined by least-square analysis, as explained in this chapter.

When values of environmental factors are not given or cannot be obtained from auxiliary information, the equation is printed out.

When the values for the environmental factors are given or can be obtained from the input query, they are placed into the stored equations, which are then evaluated for the test unit property in question. As in the graphical case, when all of the test unit's properties are evaluated and compared against their respective upper and lower bounds for satisfactory test unit operation, the computer predicts whether or not the test unit will function acceptably in the given environmental situation.

As noted in the paragraph above, the case may arise where the value of the environmental factors of the query are not actually given in the input; however, information given on climatic region and time of the year may allow evaluation of the environmental factors from charts (as in Chapter IV), or from analytical expressions of environmental factors as a function of month of the year for the various climatic regions.

A block diagram of the stored relationship application routine is presented in Figure 6-16. Note that the diagram considers only the qualitative information and analytical expression cases. The tabular and graphical data cases are omitted as they would appear similar to the quantitative relationship case in block diagram notation.

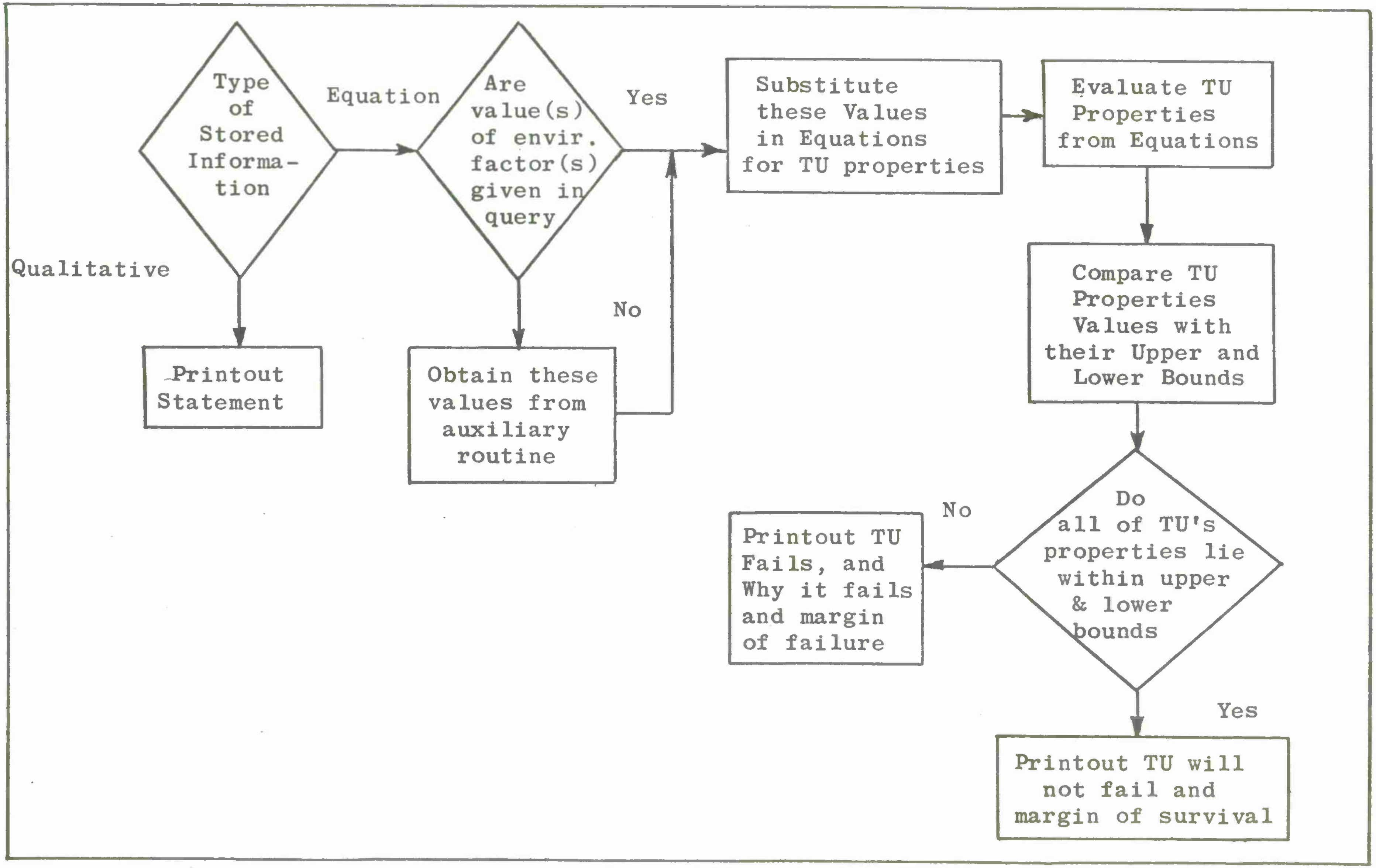

Figure 6-16. Block Diagram of Stored Relationship Application Routine

Since the application of stored relationships is an essential aspect of the computerized environmental-effects prediction system, examples illustrating several cases of operations are presented below to give a clear picture of the system in making a prediction.

<u>Example 1</u> - Value of environmental factor given.

Assume a query is asked on test unit "T", which has properties P_1 and P_2 essential to its satisfactory operation (these properties may be given with the query or determined from an auxiliary routine). The test unit will be subjected to sequential environmental factor XY (X=20, Y=40). The matrix cells for test unit "T", properties P_1 and P_2, and environmental factor XY (sequential) have been located and the following equations are stored in them.

$$G_{P_1}(X,Y) = X^2 - 5XY + 5Y^2 + 2500 \tag{93}$$

$$G_{P_2}(X,Y) = X^3 - 2X^2Y - XY^2 + 2Y^3 + 1250 \tag{94}$$

$$F_{3_{P_1}}(X,Y) = -5XY \tag{95}$$

$$F_{3_{P_2}}(X,Y) = -2X^2Y - XY^2 \tag{96}$$

$$R_{P_1}(X,Y) = \frac{-5XY}{X^2 - 5XY + 5Y^2 + 2500}$$

$$R_{P_2}(X,Y) = \frac{-2X^2Y - XY^2}{X^3 - 2X^2Y - XY^2 + Y^2 + 2Y^3 + 1250} \tag{97}$$

where:

$G_{P_1}(X,Y)$ and $G_{P_2}(X,Y)$ are the equations for the values of properties P_1 and P_2 of test unit "T", respectively, as a function of the sequential environmental factors, XY.

$F_{3_{P_1}}(X,Y)$ and $F_{3_{P_2}}(X,Y)$ are the equations for the additional changes, due to synergism, in the values of properties P_1 and P_2 of test unit "T" respectively, as a function of the sequential environmental factor, XY, and,

$R_{P_1}(X,Y)$ and $R_{P_2}(X,Y)$ are the equations for the ratio of synergistic property value change to property value for properties P_1 and P_2 of test unit "T", respectively, as a function of the sequential environmental factor, X Y.

Also stored in the matrix cells are the following bounds for properties P_1 and P_2, respectively, in which test unit "T" will function satisfactorily:

$$3{,}500 < P_1 < 7{,}500 \tag{98}$$

$$5{,}000 < P_2 < 10{,}000 \tag{99}$$

The computer substitutes X = 20, y = 40 into Equations (93) through (97) to obtain:

$$G_{P_1}(20,\ 40) = 6{,}900 = P_1 \tag{100}$$

$$G_{P_2}(20,\ 40) = 9{,}250 = P_2 \tag{101}$$

$$F_{3_{P_1}}(20,\ 40) = -4{,}000 \tag{102}$$

$$F_{3_{P_1}}(20,\ 40) = -64{,}000 \tag{103}$$

$$R_{P_1}(20,\ 40) = -\ .58 \tag{104}$$

and

$$R_{P_2}(20,\ 40) = -\ 6.92. \tag{105}$$

The property values for P_1 and P_2 given by Equations (100) and (101) are next compared with their respective upper and lower bounds given by Equations (98) and (99). It is seen that both P_1 and P_2 lie within the respective upper and lower bounds; hence, test unit "T" should perform satisfactorily in sequential environmental factor X Y with X = 20 and Y = 40.

The following information and prediction are printed out by the computer in answer to the query:

- Test Unit "T" will perform satisfactorily in sequential environmental factor X Y (X = 20, Y = 40).

- The value of Property P_1 of Test Unit "T" in sequential environmental factor X Y (X = 20, Y = 40) is 6,900, which lies within the satisfactory operation limits of 3,500 to 7,500.

- The value of property P_2 of Test Unit "T" in sequential environmental factor X Y (X = 20, Y = 40) is 9,250, which lies within the satisfactory operation limits of 5,000 to 10,000.

- The value of the change in property P_1 of Test Unit "T" due to synergism, $F3_{P_1}$ (X, Y) of sequential environmental factor X Y (X = 20, Y = 40), is - 4,000.

- The ratio of the change in Property P_1 of Test Unit "T", due to synergism, divided by the value of Property P_1 of Test Unit "T" for sequential environmental factor X Y (X = 20, Y = 40), is - .58.

- The value of the change in Property P_2 of Test Unit "T", due to synergism, $F3_{P_2}$ (X Y) of sequential environmental factor X Y (X = 20, Y = 40), is - 64,000.

- The ratio of the change in Property P_2 of Test Unit "T", due to synergism, divided by the value of Property P_2 of Test Unit "T" for sequential environmental factor X Y (X = 20, Y = 40), is - 6.92.

<u>Example 2</u> - Climatic Region and Month of Year Given.

Assume a query is asked on test unit "T", which has properties P_1 and P_2 which are essential to its satisfactory operation. The test unit will be subjected to climatic region "A" for the month of March. The environmental factors present in this region and their values are not given. They are to be determined by the computer. The computer searches its auxiliary information storage for climatic region "A". Under this region it has listed the environmental factors: X Y combined and Z single as the predominant environmental factors for this climatic region. Also listed here are the values of combined environmental factor X Y and single environmental factor Z for the month of March. They are:

- o $X = 80, Y - 30$
- o $Z = 60.$

The computer picks out these environmental factors and their values and feeds them into the input to the environmental factor - test unit matrix search. The computer now locates the matrix cells corresponding to test unit "T"; properties P_1 and P_2 and environmental factors, X Y (combined), and Z (single). The following equations are stored in the cells:

$$G_{P_1}(X,Y) = X^2 - 5.5XY + 5Y^2 + 2500 \tag{106}$$

$$G_{P_2}(X,Y) = X^3 - 6X^2Y + 10XY^2 + 2Y^3 + 1250 \tag{107}$$

$$F_{3P_1}(X,Y) = -5.5XY \tag{108}$$

$$F_{3P_2}(X,Y) = -6X^2Y + 10XY^2 \tag{109}$$

$$R_{P_1}(X,Y) = \frac{-5.5XY}{X^2 - 5.5XY + 5Y^2 + 2500} \tag{110}$$

$$R_{P_2}(X,Y) = \frac{-6X^2Y + 10XY^2}{X^3 - 6X^2Y + 10XY^2 + 2Y^3 + 1250} \tag{111}$$

$$F_{P_1}(Z) = 5Z^3 - 200Z^2 - 5{,}000Z + 2500 \tag{112}$$

$$F_{P_2}(Z) = 30Z^2 - 1700Z + 1250 \tag{113}$$

where:

$G_{P_1}(X,Y)$ and $G_{P_2}(X,Y)$ are the equations for the values of properties P_1 and P_2 of test unit "T", respectively, as a function of the combined environmental factor, XY.

$F_{3P_1}(X,Y)$ and $F_{3P_2}(X,Y)$ are the equations for the additional changes, due to synergism, in the values of properties P_1 and P_2 of test unit "T", respectively, as a function of the combined environmental factor, XY.

$R_{P_1}(X,Y)$ and $R_{P_2}(X,Y)$ are the equations for the ratio of synergistic property value change to property value for properties P_1 and P_2 of test unit "T", respectively, as a function of the combined environmental factor, XY.

$F_{P_1}(Z)$ and $F_{P_2}(Z)$ are the equations for the values of properties P_1 and P_2 of test unit "T", respectively, as a function of the single environmental factor, Z.

Also stored in the matrix cells are the following bounds for properties P_1 and P_2, respectively, in which test unit "T" will function satisfactorily

$$3,500 < P_1 < 7,500 \tag{114}$$

$$5,000 < P_2 < 10,000 \tag{115}$$

The computer substitutes X = 80, Y -30 in Equations 106 through 111 and Z= 60 in Equations 112 and 113 to obtain:

$$GP_1(80,\ 30) = 200 \tag{116}$$

$$GP_2(80,\ 30) = 135,250 \tag{117}$$

$$F_{3P_1}(80,30) = -13,200 \tag{118}$$

$$F_{3P_2}(80,30) = -432,000 \tag{119}$$

$$R_{P_1}(80,30) = -66 \tag{120}$$

$$R_{P_2}(80,30) = -3.27 \tag{121}$$

$$F_{P_1}(60) = 62,500 \tag{122}$$

$$F_{P_2}(60) = 7,250 \tag{123}$$

The property values for P_1, given by Equations 116 and 122 for environmental factors XY (combined) and Z (single) respectively, are compared with the upper and lower bounds for property P_1 in Equation 114. Also the property values of P_2, given by Equations 117 and 123 for environmental factors XY (combined) and Z (single) respectively, are compared with the upper and lower bounds for property P_2 in Equation 115. It is seen, for combined environmental factor XY, that both P_1 and P_2 lie outside their respective upper and lower bounds for satisfactory operation. Hence, test unit "T" should not function satisfactorily in combined environmental factor XY with X=80 and Y=30. Furthermore, for the single environmental factor Z, P_1 lies outside the upper and lower bounds for satisfactory operation, while P_2 lies within the bounds. Hence, since one of the test unit's properties strayed outside the bounds, test unit "T" should not function satisfactorily in single environmental factor Z with Z=60. Since test unit "T" should not function satisfactorily in the predominant environmental factors present in climatic region "A", at their respective levels for the month of March, test unit "T" should not function satisfactorily in climatic region "A" in the month of March.

The following information and prediction is printed out by the computer in answer to the query:

o TEST UNIT "T" WILL NOT PERFORM SATISFACTORILY IN CLIMATIC REGION "A" IN THE MONTH OF MARCH.

o THE PREDOMINANT ENVIRONMENTAL FACTORS OF CLIMATIC REGION "A" ARE:

1. XY (COMBINED)
2. Z (SINGLE)

o THE NUMERICAL VALUE OF COMBINED ENVIRONMENTAL FACTOR XY IN CLIMATIC REGION "A" FOR THE MONTH OF MARCH IS X= 80, Y = 30.

o THE NUMERICAL VALUE OF SINGLE ENVIRONMENTAL FACTOR Z IN CLIMATIC REGION "A" FOR THE MONTH OF MARCH IS Z = 60.

o THE VALUE OF PROPERTY P_1 OF TEST UNIT "T" IN COMBINED ENVIRONMENTAL FACTOR XY (X = 80, Y = 30) IS 200, WHICH LIES BELOW THE SATISFACTORY OPERATION LIMITS OF 3,500 to 7,500.

o THE VALUE OF PROPERTY P_2 OF TEST UNIT "T" IN COMBINED ENVIRONMENTAL FACTOR XY (X = 80, Y = 30) IS 135,250, WHICH LIES ABOVE THE SATISFACTORY OPERATION LIMITS OF 5,000 to 10,000.

o THE VALUE OF THE CHANGE IN PROPERTY P_1 OF TEST UNIT "T", DUE TO SYNERGISM, F_{3P_1} (X,Y) OF COMBINED ENVIRONMENTAL FACTOR XY (X = 80, Y = 30), IS -13,200.

o THE RATIO OF THE CHANGE IN PROPERTY P_1 OF TEST UNIT "T", DUE TO SYNERGISM, DIVIDED BY THE VALUE OF PROPERTY P_1 OF TEST UNIT "T" FOR COMBINED ENVIRONMENTAL FACTOR XY (X = 80, Y = 30), IS -66.

o THE VALUE OF THE CHANGE IN PROPERTY P_2 OF TEST UNIT "T", DUE TO SYNERGISM, F_{3P_2} (X, Y) OF COMBINED ENVIRONMENTAL FACTOR XY (X = 80, Y = 30), IS -432,000.

o THE RATIO OF THE CHANGE IN PROPERTY P_2 OF TEST UNIT "T", DUE TO SYNERGISM, DIVIDED BY THE VALUE OF PROPERTY P_2 OF TEST UNIT "T" FOR COMBINED ENVIRONMENTAL FACTOR XY (X = 80, Y = 30), IS -3.27.

o THE VALUE OF PROPERTY P_1 OF TEST UNIT "T" IN SINGLE ENVIRONMENTAL FACTOR Z (Z = 60) IS 62,500, WHICH LIES ABOVE THE SATISFACTORY OPERATION LIMITS OF 3,500 to 7,500.

o THE VALUE OF PROPERTY P_2 OF TEST UNIT "T" IN SINGLE ENVIRONMENTAL FACTOR Z (Z = 60) IS 7,250, WHICH LIES WITHIN THE SATISFACTORY OPERATION LIMITS OF 5,000 to 10,000.

CHAPTER VII

SYSTEM PILOT EXERCISE

Objective of Pilot Exercise

The purpose of a system pilot exercise is twofold; it tests the system's capabilities, and demonstrates the system's operation. From the pilot exercise, the system logic can be checked and debugged. The actual implementation of the system in the pilot exercise serves to expose shortcomings of the system which may have been overlooked in its theoretical development. Also, a more comprehensive concept of the storage, search, and analysis routines of the system is developed from seeing the system in operation.

The pilot exercise is not all-inclusive. It does present many of the system's possible capabilities; however some of these are done in steps which are not tied together as they would be by the actual full scale system. It should also be noted that the exercise deals with only a limited segment of the full scale test unit -environmental factor matrix.

For the pilot exercise, it was decided to limit the test units used to the various types of rubbers. This is only one category of the materials level. The reason for this was to allow some depth in the analysis of environmental effects on a test unit. Since the pilot exercise was on a limited scale, it was more advantagous to limit the demonstration to one type of test unit, and cover this test unit in great detail. Rubbers were selected for their numerous varieties (permitting comparison of environmental effects), and for data availability.

A search for data on environmental effects on the various types of rubber was made, resulting in various relationships of properties of rubbers versus environmental factors.

Storage, Search and Prediction for Pilot Exercise

The information obtained for the pilot exercise was stored in three matrix formats, each corresponding to a different form of information. Two were of the auxiliary type, the third was a section of the test unit - environmental factor matrix.

The first type of auxiliary information is that on predominant environmental factors in a climatic region, including quantitative values for the environmental factors for the various months of the year. This is illustrated in tabular form in Chapter IV. In actual use, such information would be used to determine the environmental factors present and their quantitative value in a climatic region, to assist in an environmental-effects prediction query. For the demonstration run, however, specific queries are asked on environmental factors in a climatic region, to test if this routine operates satisfactorily.

The second type of auxiliary information for the pilot exercise is a matrix of the properties of the various types of rubbers, including numerical values for ambient conditions where possible. (Qualitative statements are also included.) The types of rubbers considered are shown in Figure 7-1.

The type of information is a matrix of types of rubbers and their properties vs. environmental factors. In this matrix is stored the analytical, graphical, and tabular quantitative information as well as qualitative statements used for predictions on the effects of environmental factors on test units. The cells of the matrix are given a coded location number which corresponds to the coded number on the storage location of the actual information. An example of a section of the matrix is shown in Figure 7-2.

. Natural rubber
. Synthetic polyisoprene
. Styrene butadiene
. Stereo SBR
. Butyl
 	
. Polyisobutylene
. Chlorobutyl
. Polybutadiene
. Ethylene propylene
. Neoprene
	. Nitrile
	. Polysulfide
	. Polyurethane
	. Silicone
	. Chlorosulfonated polyethylene
	
	. Polyacrylic
	. Fluoroelastomers
	  - Viton, Fluorels
	  - Fluorosilicone
	  - Kel-F
	
	. Methyl rubber
	. Thermoprene
	. Chlorinated rubber

The properties of the rubbers considered are:	

. Specific gravity
. Thermal conductivity
. Coefficient of thermal expansion
. Electrical insulation
. Flame resistance
 	
. Cold resistance
. Recommended service temperature
  - minimum
  - maximum
. Dielectric strength
 	
. Electric conductivity
. Tensile strength
  - pure gum
  - black
	. % Elongation
	  - pure gum
	  - black
	
	. Hardness (Durometer A)
	. Rebound
	  - cold
	  - hot
	. Tear resistance
	
	. Abrasion resistance
	  - normal
	  - oil soaked
	
	. Adhesion
	  - to metals
	  - to fabrics.

Figure 7-1. Types of Rubber considered in Pilot Exercise

	ENVIRONMENTAL FACTORS					
Types of Rubbers (Properties)	Immersion in 50/50 Hydrazine /UDMH at Room Temp.	Temp.	Immersion in 50/50 Hydrazine /UDMH Combined W/Temp.	Immersion in MMH combined W/Temp.	Immersion in MHF-1 combined W/Temp.	Immersion in MHF-Y combined W/Temp.
Butyl Rubber	A 1,2,3,4	AA 1,2,3,4	AB 1,2,3,4			
-Tensile Strength	A 1	AA 1	AB 1			
-% Elongation	A 2	AA 2	AB 2			
-Hardness	A 3	AA 3	AB 3			
-% Volume Change	A 4	AA 4				
Polybutadiene	B 1,2,3,4	BA 1,2,3,4				
-Tensile Strength	B 1	BA 1				
-% Elongation	B 2	BA 2				
-Hardness	B 3	BA 3				
-% Volume Change	B 4	BA 4				

Figure 7-2. Example of Test Unit Environmental Factor Matrix.

The types of queries used for the pilot exercise are listed below:

Class 1: What are the pertinent environmental factors and their ranges for all months for a specified climatic region?

Class 2: What are the pertinent environmental factors in a specific climatic region?

Class 3: What is the value, under average ambient conditions, of a particular property of a specified test unit?

Class 4: What are the values, under average ambient conditions, of all the properties for a specified test unit?

Class 5: What is the value of the tensile strength of nitrile rubber when subjected to gamma radiation of a specified intensity at atmospheric conditions?

Class 6: What is the percent elongation of nitrile rubber when subjected to gamma radiation of a specified intensity at atmospheric conditions?

Class 7: What is the value of the tensile strength of nitrile rubber when subjected to gamma radiation of a specified intensity when at a constant vacuum level of 5×10^{-5} torr?

Class 8: What is the percent elongation of nitrile rubber when subjected to gamma radiation of a specified intensity when at a constant vacuum level of 5×10^{-5} torr?

Class 9: What is the percentage change in the peak acceleration transmission of polyurethane flexible foam cushioning material of specified thickness at a specified temperature?

The queries of classes 1 and 2 utilize the tables of environmental factors in a climatic region. These types of queries usually are not asked alone, but are generated by the computer to obtain the environmental factors of a prediction query on a climatic region.

The queries of classes 3 and 4 utilize the matrix of test units vs. properties. These types of queries are usually not asked alone, but are generated by the computer to obtain the properties of a test unit in question and/or the value of the property under average ambient conditions.

The queries of classes 5 through 9 utilize the test unit - environmental factor matrix to locate analytical expressions for test unit properties as a function of an environmental factor. With specific values given for the environmental factors, the test unit property values are calculated.

The method utilized for this routine in the pilot exercise has the computer search the matrix for the correct test unit (property) - environmental factor cell which indicates the code number of the cell. This code number identifies the storage location of the desired analytical expression, which is then located. The value of the environmental factor is substituted into the expression which is then evaluated for the test unit property value.

Query classes 5 and 7 are used together to point out any synergistic effect on the tensile strength of nitrile rubber due to radiation and vacuum acting in combination as opposed to radiation alone.

Similarly, query classes 6 and 8 are used to illustrate the synergistic possibilities of radiation and vacuum acting in combination on the percent elongation of nitrile rubber.

Query class 9 is used to illustrate an environmental effects situation currently schedule for testing at Frankford Arsenal to validate the data predicted.

Summary Discussion of Pilot Exercise

Although the pilot exercise is done on a limited scale with limited data, it definitely illustrates the feasibility of such a system. The basic needs of the system are brought out by the exercise. The first of these is the need for data. One of the governing limitations on the prediction system is the lack of quantitative data, especially on combined and sequential environmental factor effects. This points out the definite need for combined and sequential environmental testing on test units. Another indicated need is a storage routine capable of storing the huge amount of information which the large scale system will hold, so that it may be recalled with a minimum time loss. The scheme used for the pilot exercise utilizes only the computer's core storage which can handle only a limited amount of storage. Methods utilizing disc storage, magnetic tape and drum storage must be investigated for their efficiency in the case of large scale storage.

Another fact brought to light by the pilot exercise is the benefit of storing analytical expressions for the environmental effects on test units, rather than graphs or tables. The graphs are much more unwieldly to handle by computer means, and tables are less accurate and require more storage space.

CHAPTER VIII

TESTS

Contribution of Tests to System Capability

The performance of specific environmental tests, as an adjunct activity to the computerized system, contributes basically to the total system predictive capability. Such tests can be designed to:

1. Supplement analytical development of synergistic effects of combined and sequential environments.

2. Confirm or correct predictions based on limited existing data.

3. Pinpoint those test unit/environment factors most significant in the effects-mechanism.

4. Quantify the computer prediction otherwise limited to a qualitative analysis.

5. Provide complex data for programming a broader computer predictive capability.

In practice, the response of the analytical simulator to a specific query would indicate the necessity of performing a particular test.

Candidate Demonstration Tests

To provide back-up data on various test unit/environment combinations representative of those to be handled by the analytical simulator, particular tests of these combinations were suggested for performance at the Frankford Arsenal test facility. These included:

a. Cadmium-plated wire spring under vibration and corrosive atmosphere.

b. Compression spring under vibration and high temperature.

c. Rubber O-Ring under stress and ozone concentration.

d. Polyurethane foam cushioning under low temperature and shock load.

e. Nut - bolt joint under vibration and high temperature.

Of these various candidates, tests (c) and (d) were selected for actual performance.

<u>Predicted Results of Demonstration Tests</u>

Test (c) will provide quantitative data to validate primary qualitative conclusions of the time-variant deleterious synergistic effect on rubber under stress, when simultaneously exposed to a high ozone concentration. Under zero stress, the effect of ozone on the rubber surface should be negligible. At low stress level, the exposure to ozone should produce a few surface cracks of minor degree. At a high stress level the rubber should exhibit relatively more severe cracking, both in quantity and depth.

Test (d) will confirm predictions, based on qualitative deduction and limited existing data, regarding the synergistic effect of low temperature on the shock-cushioning efficiency of polyurethane flexible foam. At room temperature, the shock load transmitted through the cushioning material is considered at a "normal" datum level. At 20°F., the shock load transmitted could be expected to increase by approximately 35%, for two-inch thick material. At - 10°F., the increase in shock transmission could be expected to approximate 110%, for two-inch thick material. As the cushioning thickness is increased, the shock transmitted could be expected to decrease linearly by the ratio of the thicknesses.

CHAPTER IX

CONCLUSIONS AND RECOMMENDATIONS

The spadework accomplished thus far has laid the groundwork and developed the framework of the computerized prediction system as herein described. It further permits the following conclusions and recommendations regarding the system's practicality and usefulness, its potentialities and its limitations, and system characteristics that influence its future implementation in the field of environmental effects prediction:

Conclusions:

1. A practical, usable computerized system is feasible for predicting the effects of combined and sequential environments on the properties and operating characteristics of materials and equipments.

2. The computerized system may be adapted to include any given environmental situation and any given material or equipment, as well as any desired level of assembly of the equipment.

3. Predictions of environmental effects may be either qualitative or quantitative in nature.

4. Predictions of environmental effects are limited by the amount of input source data available regarding the subject phenomenon.

5. The nature of the computerized prediction system permits its use by a complete range of potential users, from research and development personnel to equipment commanders in the field.

6. The large scope of the total prediction problem makes feasibility of the computerized system dependent on standardization of test unit and environmental factor categories, to reduce storage volume.

7. From view of accuracy, handling ease, and storage economy, the use of analytical formulas is particularly appropriate for prediction of property variations by the computerized system.

8. Currency of prediction output by the computerized system depends on continuous updating and revision of input data.

9. The non-linearity of synergistic behavior makes the use of a computerized system, capable of performing complex calculations, particularly applicable.

Recommendations:

1. To handle the voluminous data encompassed in a computerized prediction system, an efficient storage method that allows quick retrieval, other than the computer's core, should be developed.

2. The analytical model for predicting environmental effects must, in most instances, introduce time as one of the variables affecting test unit behavior under the duration of the environmental exposure. Future development of a prediction system should include work on this basic factor.

3. For purposes of predicting reliability, the existing, deterministic system model should be expanded to yield probabilistic predictions of environmental effects.

4. Implementation of the proposed prediction system should be initiated on a small scale, covering only those test units and environmental factors of primary interest to the user.

CHAPTER X

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13. ABSTRACT

This project applies advanced techniques to determine the environmental competence of materials and equipments under combined and sequential environments experienced by Army systems and components in field operation. The critical aspect of environmental interaction, is thoroughly treated and integrated into the overall approach.

A plan is presented for receiving, organizing, and operating on the problem elements to yield the desired output of environmental effects prediction. The plan is specifically designed for computerization. The rationale is set forth in a logical, and comprehensive framework that may be readily understood and implemented by the potential user. A pilot exercise of the computerized prediction system gives specific examples of the system operation in specific instances.

Finally, conclusions and recommendations are offered regarding system practicality, usefulness, potentialities and limitations, and the guideposts presented for future action in the field of environmental effects prediction.

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